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INITIAL WATERSHED ASSESSMENT
WATER RESOURCES INVENTORY AREA 9
GREEN-DUWAMISH WATERSHED

Open-File Report 95-01

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January 20, 1995

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INTRODUCTION

Initial Watershed Assessments

The Washington Department of Ecology Water Resources Program is charged with managing the state's water resources to ensure that they are protected and used for the greatest public benefit. One of the components of this water management is permitting for the use of surface and ground water. Historically, the Program has evaluated most water right applications on a case-by-case basis and, increasingly, this has become an inefficient way to deal with the large numbers of applications received. Furthermore, individual permit review usually required relying on the results of relatively short duration pump tests in order to make long term resource decisions. This approach frequently has resulted in ignoring the cumulative impacts that many individual pumping wells may have on surface water flows. These Initial Watershed Assessments (IWAs) are part of an effort to evolve the permitting of water rights to consider the environmental health of the entire watershed system.

These assessments focussed on assembling and reviewing existing information; no new data were collected. The information assembled was chosen to broadly indicate the overall condition of water resources within the watershed, including water quantity, hydrogeology, water demand, and water quality, as well as the relative health of aquatic ecosystems.

The Green-Duwamish Watershed

Washington is divided into 62 Water Resource Inventory Areas (WRIAs) delineating the major drainage networks-that flow into the Columbia River, the Pacific Ocean, and Puget Sound (Figure 1). The Green-Duwamish Watershed (WRIA 9), in southern King County, drains a section of the west slope of the Cascades into Puget Sound at Seattle. Chapter 173-509 Washington Administrative Code (WAC) established instream flows for this WRIA.

WATERSHED DESCRIPTION

Area Description

The Green River begins in the Cascade Mountains near Stampede Pass and flows west through the Snoqualmie National Forest. Thirty miles downstream from its source, the river encounters Howard A. Hansen (Hansen) Dam at river mile (RM) 64.5 and then the Tacoma Water Diversion Dam at RM 61. The river continues to the town of Kanasket and the start of the Green River Gorge. Two major tributaries, Newaukum Creek (at RM 40.7) and Big Soos Creek (at RM 33.7) join the Green River upstream from Auburn. The river turns northward at Auburn and flows through Kent and Tukwila, becoming the Duwamish River at RM 11. The river changes names at the former confluence of the Green and Black Rivers, even though regrading of the surface has obliterated the channel of the Black. The entire Green-Duwamish Watershed encompasses approximately 700 square miles, including the 72 mile Soos Creek and the 27 mile Newaukum Creek Subbasins (Figure.2).

Historically, the U.S. Geological Survey has operated a total of 24 stream gaging stations in WRIA 9, of which seven are located on the main stem of the Green River. The two most important of these gages are located at Palmer (USGS Station No. 12106500) and at Auburn (USGS Station No. 12113000) because these are the two points within this WRIA where Ecology has established minimum instream flows (Chapter 173-509 WAC). The Palmer gage measures the flow below the Tacoma Diversion Dam and the Auburn gage measures flow from a 408 mile' area of the upper Green River watershed, including the Newaukum and Soos Creek subbasins, where the river enters the most densely populated and heavily industrialized part of the WRIA.

Land Cover and Land Use

The King County Watershed Ranking Final Report (King County 1989), divided the Green River Watershed into Upper, Middle, and Lower Green River Watersheds, and the Soos Creek Watershed. The Upper Green River Watershed, the area above the Hansen Dam, is managed by the City of Tacoma and the U.S. Forest Service to protect the quality of the water supply for Tacoma. The area 'is closed to the public, however there is extensive logging activity.

The Middle Green River Watershed includes Coal Creek, Deep Creek, Middle Green River, and Newaukum Creek and is comparatively sparsely populated. Coal Creek, Deep Creek, and Newaukum Creek's headwaters are in the Cascade foothills where the primary land use is managed forest. In the Lower Newaukum Creek Subbasin, dairy farming is the most prevalent land use and is likely to continue for the foreseeable future. Other land uses include beef cattle raising, crop farming, racehorse breeding and training, and single family residences.

The Soos Creek Subbasin includes Big Soos Creek with its main tributaries Little Soos Creek, Soosette Creek, Covington Creek and Jenkins Creek. The southern and eastern portions of the watershed are mostly rural. The north and west portions of this area have been designated for urban-density development by the 1985 King County Comprehensive Plan (King County 1985). This area is experiencing some of the fastest residential and commercial development in King County.

The Lower Green River Watershed contains the wide flood plain of the lower Green and Duwamish Rivers and includes the cities of Renton, Tukwilla, Kent, and Auburn. Land use has shifted almost entirely from rural farming to commercial and industrial during the last 25 years.

Climate and Precipitation Trends

The climate is typical of the mid-latitude, Pacific marine type. The prevailing winds move moist air inland from the Pacific Ocean, moderating temperatures in both winter and summer. Rains come primarily in the winter and the summers tend to be dry. The maritime air cools as it pushes up against the Cascade Range, rising to the condensation point, and forming rain or snow. The precipitation is greater and the temperatures are lower in 'the Cascade Range highlands than in the Puget Sound lowlands. Fifty percent of the annual precipitation falls in the four-month period from October through January, and seventy-five percent in the six months between October and March.

Average annual precipitation ranges from about 38 inches at SeaTac (elevation 386 feet), to over 92 inches at Stampede Pass (elevation 3,700 feet) (Figure 3). The moving 3-year average of 1951 to 1992 yearly precipitation at the SeaTac weather station is indicated in Figure 4. The moving 3-year average of 1933 to 1992 yearly precipitation at the Palmer weather station (elevation 895 feet) is indicated in Figure 4. The Palmer station's mean annual precipitation for the 60-year record was 91 inches. In general, the graphs indicate that annual precipitation at both weather stations was generally higher than average during the mid-1940s through the mid-1970s, and has been lower than average since then.

HYDROGEOLOGY

Hydrology

Ultimately, all of the surface and ground water in the Green-Duwamish Watershed comes from precipitation as rain or snowmelt. A fraction of the precipitation evaporates back to the atmosphere or is consumed by plants (evapotranspiration). Some precipitation occurs as snow and accumulates at higher elevations to form winter snowpack. Each spring and summer, the meltwater from this snow combines with rainfall to provide surface runoff to the Green River system. However, a significant portion of the snowmelt and rainfall also infiltrates downward into the soil to become ground water. Eventually, some of this ground water discharges into the river and its tributaries, thereby supplying most of the river flow during late summer through the winter. The hydrologic cycle is illustrated schematically in Figure 5.

Ground water will discharge to the Green River system when the water table is higher than the surface water level. This occurs throughout the study area, but is especially. true in the upper reaches of the watershed. Conversely, the Green River and its tributaries lose water to ground water aquifers when the stream level is higher than the water table. Depending on the direction of the hydraulic gradient, well pumping can either reduce the amount of water discharging to the river or increase the quantity of water leaking out of the river.

Other than the sources mentioned above, the only other notable ground water recharge within the study area is due to water which seeps from Lake Youngs. The lake is currently used as a reservoir storing Cedar River water (WRIA 8), thus the seepage constitutes a source of water from outside of the Green-Duwamish Watershed.

Geology and Ground Water

Approximately half of the study area, primarily the portion east of Palmer, is mantled by volcanic and sedimentary rocks. Most of these rocks are either too fine-grained or too highly altered to yield more than 50 gallons per minute (gpm). The remaining portion of the study area is characterized mainly by a thick sequence of unconsolidated Quaternary-aged glacial and alluvial deposits that form aquifer units which yield economical quantities of ground water. Table 1 summarizes the stratigraphy of these deposits.

The geology of the western portion of the study area was discussed in the 1989 South King County Ground Water Management Plan (GWMP 1989a; SKCWAC 1989). The GWMP divides the Lower Green-Duwamish Watershed into four sub-areas, these areas include the Covington Upland Des Moines Upland, Federal Way Upland, and Green River Valley.

The Covington Upland, which is drained by Soos Creek, is bounded. by the Green River to the west and south, and the Cedar River to the north. It can be thought of as a paleo-bedrock foothill of the Cascade Range mantled- by a wedge of Pleistocene glacial deposits. The thickness of these sediments apparently ranges from zero in the extreme southeast to 1,200 feet in the western portion of the upland. This westerly thickening wedge is complicated by an east-west trending,

Table 1

Nomenclature and Regional Correlation of Stratigraphy
South King County

Unit Symbol	Stratigraphic Sequence	Suggested Regional Correlation	Geologic Character
Qal	Recent Alluvium	Quaternary Alluvium	Principally fine grained sand, silt, clay, and peat. Clean sand and gravel deposits locally occur in vicinity of the White River near Auburn and the Cedar River upstream of Renton.
Qom	Osceola Mudflow	Osceola Mudflow	Unsorted mixture of andesite rock fragments and wood in a clayey sand matrix. Large boulders near the base. Occurs primarily in the southern portion of the study area.
Qvr	Vashon Recessional Outwash	Vashon Recessional Outwash	Well-sorted sand and gravel deposits. Includes outwash plain, valley train, delta, and ice-contact kame and kame terrace deposits. Qvrl is a fine grained subset where material was locally deposited in recessional lakes.
Qvt	Vashon Till	Vashon Till	Compact mixture of gravel and occasional boulder in a gray clayey, silty sand matrix. Locally includes some cleaner sand and gravel lenses. Occurs typically as an undulating carpet at the ground surface in south King County.
Qva	Vashon Advance Outwash	Vashon Advance Outwash, Colvos Sand, Esperance Sand	Predominantly sand and gravelly sand in Des Moines Upland. Usually has a higher percentage of gravel in most other portions of the study area. May locally include very fine sand and silt.
Qvl	Lawton Clay	Lawton Clay	Lacustrine deposits primarily composed of clay, silt, and fine sand deposited in the Vashon pro-glacial lake. More widespread in north King County than in the study area.
Qvu	Undifferentiated Vashon Deposits	Undifferentiated Vashon Deposits	An assortment of deposits including till, outwash, and lacustrine deposits that were deposited during the Vashon Stade of the Frazer Glaciation.
Qf(1)	First Fine Grained Unit	Olympia Interglacial	Principally fine-grained fluvial and lacustrine deposits consisting of sand, silt, clay, and peat. May locally contain some sand and gravel deposits.

Table 1 (continued)

Unit Symbol	Stratigraphic Sequence	Suggested Regional Correlation	Geologic Character
Qc(2)	Second Coarse Grained Unit	Possession Drift, Double Bluff Drift	Principally granular soils and till with a relatively fresh appearance. This unit is difficult to distinguish from Vashon Till in outcrop. Found only in the Covington upland where it is an important groundwater aquifer. Tentatively correlated with the Possession Drift suggesting that the Double Bluff advance did not reach as far south.
Qf(2)	Second Fine ' Grained Unit	Whidbey Formation, Kitsap Formation	Principally fine grained fluvial and lacustrine deposits consisting of sand, silt, clay, and peat. May locally contain some sand and gravel deposits.
Qc(3)	Third Coarse Grained Unit	Salmon Springs Drift	Typically recognized by its oxidized character both in outcrop and in well logs (rusty Gravel). Occurs ubiquitously in all upland subareas in this study. An important source of groundwater in south King County.
Qf(3)	Third Fine Grained Unit	Puyallup Formation .	First recognized by Willis which he labeled the Puyallup Sand. Later upgraded to Formation status by Crandell. Composed chiefly of fine to medium sand derived from Mt. Rainier. The andesitic source gives the Puyallup Fm. its characteristic purple tinge. Usually is found around sea level in south King County/
Qc(4)	Fourth Coarse Grained Unit	Uncertain	Coarse grained deposits
Qf(4)	Fourth Fine Grained Unit	Uncertain	Fine grained deposits
Qf(u)	Older Undifferentiated Fine Grained Unit	Uncertain	Fine grained deposits
Qc(u)	Older Undifferentiated Coarse Grained Unit	Uncertain	Coarse grained deposits
Qu	Undifferentiated Deposits	Uncertain	Highly variable in character
Tbr	Tertiary Bedrock	Puget Group	Principally arkosic, micaceous sandstone and interbedded shale and coal. Locally includes thick sequence of volcanic sandstone and conglomerate, tuffaceous siltstone, tuffbreccia, and lava flows.

Source: South King County Ground Water Management Plan (SKCGWAC 1989).

buried sandstone ridge along the. northern edge of the upland. The ridge is important because it limits the discharge of deep ground water from the Upland to the Cedar River.

The hydrogeology of the western half of the study area is complicated due to the variable nature of the aquifers and aquitards. According to the GWMP, the principal aquifers of the Covington Upland include Qvr, Qva, Qc(2), Qc(3), and Qc(4) (shallowest to deepest). In many portions of the upland, distinguishing between the top three or four aquifers is very difficult. Consequently, for the purposes of developing the GWMP water level contour map, Qvr, Qva, and Qc(2) water level data were combined. The GWMP map indicates that the highest ground water elevations within the Covington Plateau occur within the Black Diamond and Lake Youngs areas. The recharge mound within the Lake Youngs area appears to be largely related to seepage losses from the reservoir.

The Des Moines and Federal Way Uplands occupy the upland drift plain that lies between the Green/Duwamish Rivers to the east, and the Puget Sound to the west. The Des Moines Upland occupies the north half of the drift plain, while the Federal Way Upland lies to the south. The subsurface geology in this area is dominated by glacio-fluvial sediments. Vashon glacial deposits typically extend from land surface to as deep as 150 feet; correlations between pre-Vashon stratigraphic units are not well understood. The GWMP identifies the principle aquifers in this area as Qvr, Qva, Qc(3), Qc(4), and Qc(u) (Table 1). These aquifers vary in thickness and permeablilty, with the Qva and Qc(3) being the most productive. A ground water divide runs north-south through the uplands; this divide is generally coincident with the surface water divide in this area.

The Green River Valley separates the Convington Upland from the Des Moines and Federal Way Uplands. The valley floodplain is quite flat, with a gentle slope to the north. Aquifer materials in the valley are composed of recent alluvium (Qal) and Vashon Recessional Outwash (Qvr). The Vashon outwash deposits are thickest (over 300 feet) in the east-central part of the Auburn area, and comprise a major source of ground water in the area.

Ground Water-Surface Water Interaction

The GWMP cross sections indicate that Qc(3) (one of the two deep aquifers) intersects Qc(2) and even Soos Creek itself, in places. This suggests direct hydraulic continuity between Qc(3) and the overlying shallower system. Furthermore, the cross sections indicate that Qc(3) and Qc(4) are both under artesian pressure, and that the intervening materials are merely silty clay aquitards. Consequently, pumping from either of these two deeper, semi-confined aquifers will likely increase the vertical hydraulic gradient between Qc(3) and Qc(4) and the overlying aquifers.

The GWMP (SKCGWAC, 1989) includes information on a USGS modeling study (unpublished) of the Covington Upland. The USGS model was calibrated to precipitation and runoff data for the Soos Creek Basin from data collected from 1967 through 1987. The water balance estimates include 49.5 inches per year of precipitation, 19.7 inches per year of evapotranspiration, 9.2 inches per year of runoff, and 21.6 inches per year of recharge. The results of the model suggest that the majority of upland recharge is discharged to springs or returns to Big Soos Creek via shallow aquifer baseflow. The amount of average recharge available to deeper aquifer systems was estimated to be 2 inches of precipitation, or about 10 % of total basin recharge to the Covington Upland. The USGS study concluded that discharge of ground water from the deeper aquifer system is to regional drainage features such as the Cedar and Green Rivers.

The USGS is currently finalizing a report on an analysis of the effects of ground water withdrawals on surface water bodies in small basins typical of the Puget Sound Lowland. The initial hydrogeology upon which the USGS analytical model was based is that of Big Soos Creek basin, although some of this was simplified and changed as the model was developed.

Consequently, the model should provide useful insights into the mechanics of the Soos Creek basin. Preliminary reports on that study suggest that pumping even from the deepest aquifers produces significant impacts on surface water bodies within the greater Green River basin.

The Newaukum Creek basin and vicinity are part of the Osceola Mudflow Plain. Cross sections constructed by Luzier (1969) indicate that this area's hydrogeology is fairly similar to the Covington Upland, except that large portions are covered by mudflow deposits up to 75 feet thick. Luzier's mapping indicates that much of Newaukum Creek cuts through the mudflow, thus establishing continuity between the creek and the underlying aquifers.

In the Des Moines and Federal Way Uplands, ground water discharges either to the Puget Sound (west of the divide) or to the Green/Duwamish Rivers (to the east). Several smaller surface water bodies (Miller, Des Moines, and Hylebos Creeks) appear to intercept the uppermost aquifer (Qva). Water levels in the Qva aquifer surrounding these creeks indicate that the aquifer is currently discharging to surface water in this area. Increased production from this or underlying aquifers could reverse this situation.

Ground Water Status

The three largest ground water supply areas in the Covington Upland are the Covington Water District Lake Sawyer well field, King County Water District No. 111 (KCWD 111) well field, and the Kent spring source. The Lake Sawyer well field taps the Qc(2) aquifer, which occurs throughout much of the Covington Upland and is often difficult to distinguish from the Qva aquifer. The KCWD 111 wells receive their water from the Qva and Qc(2) aquifers, which are referred to as intermediate aquifers in the GWMP. The Qva aquifer occurs primarily.in the western portion of the upland and serves many domestic wells. The shallow Qvr aquifer provides the source for the springs used by the Kent water system. The GWMP noted a decline in one of these springs, which indicates that some ground water declines are occurring within the area. The City of Kent also has wells within the deep Qc(3) and Qc(4) aquifers within the Kent area, but no water level data are available for these wells.

The GWMP states: "The data suggest there are no significant impacts associated with existing levels of development within these (Lake Sawyer well field and KCWD 111) areas. " However, the data indicated for the Lake Sawyer well field included only records from 1977 through 1988. The water levels appear stable, however most of the water level data used was collected under pumping conditions. Thus, this information is questionable, as the period of record is relatively short and pumping water level trends may have little relation to static water level trends.

The GWMP data for KCWD 111 is from Well 3, which taps the Qc(2) aquifer and is representative of wells 1 through 6. The GWMP states that the water levels initially declined about 20 to 30 feet, then stabilized to follow climatic trends. This reported stabilization at a much lower level suggests major dewatering of the aquifer, which could significantly alter the local ground water gradient. This would lead to a decrease in ground water discharge to local surface water streams such as adjacent Big Soos Creek. Unfortunately, the period of record referred to is only 3'/z years (6/84 to 12/87), thus it is really insufficient to make sound conclusions about water level trends.

Within the remainder of WRIA 9, significant water level declines were identified in the Qc(4) aquifer in the Des Moines area. and within the Qc(3) aquifer of the Federal Way Upland. Approximately five feet of water level declines may have occurred since 1990 within the Qal and Qva aquifers that underlie the Auburn area.

WATER DEMAND

History of the City of Tacoma Diversion and the Hansen Dam

Surface water is diverted from the upper Green River basin for municipal supply by the City of Tacoma. Tacoma built a water diversion dam at RM 61 on the Green River in 1911. In 1913, construction of a pipeline was completed with a capacity of 65 cubic feet per second (cfs; 1 cubic foot is approximately 7.5 gallons) and, in 1948, a second pipeline was completed adjacent to the first, for a total diversion of 112 cfs. Tacoma filed a water right claim in 1971 for a maximum of 400 cfs. In 1985, Ecology granted a water right permit to Tacoma for an additional 100 cfs diversion (priority date 1933), subject to the minimum instream flows for the Green River as set forth in Chapter 173509 WAC.

Tacoma also operates a 72 million gallon per day (mgd) (equivalent to 111 cfs) capacity well field in the North Fork Green River Valley, above the Hansen Dam. This ground water replaces a portion of Tacoma's surface water supply during periods of high river turbidity.

The U. S. Army Corps of Engineers (ACOE) began filling the Hansen Reservoir on December 5, 1961. The dam was authorized by Congress for flood control and conservation storage to augment low summer/fall flows for fisheries enhancement. The ACOE operates the dam to prevent flood flows over 12,000 cfs at Auburn and to provide a minimum flow of 223 cfs from the dam to ensure that 110 cfs passes through the Palmer gage, below the Tacoma diversion. Overall, the operation of the dam since 1962 has changed flows at Auburn by attenuating high flows in April, May, and June and augmenting low flows in July, August, September, and October.

Water Use: Water Rights and Claims

This assessment did not measure actual water use or verify water rights. Approximately 25 percent of the population of south King County draws water from small systems with five or fewer connections (SKCGWAC, 1991), and these were not accounted for in our study as they are exempt from water right permits. For the Soos Creek basin alone, Carlson (1994) estimated total withdrawals of 3,525 acre-feet per year (af/y) from exempt wells. Unauthorized water users and recorded or claimed rights no longer exercised are factors that prevent correlation between the amount of water being used and the amount of water allocated by rights. Nonetheless, the patterns in applications, claims, and permits for water rights do indicate trends in water consumption within the watershed.

A total of 860 consumptive water rights have been issued in the Green-Duwamish Watershed, and 3,330 claims for both surface and ground water were filed during the claims registration period (Table 2a). Annual quantity. (Qa) was not assigned on surface water rights issued before the 1960's, so total recorded surface water Qa is for approximately 40% of the surface water rights issued. Most claimants for water rights did not specify quantity, so this assessment estimated an instantaneous quantity (Qi) of 0.02 cfs and an annual quantity (Qa) of 1 acre-foot per year for each claim for domestic use and/or stockwatering. Claims for irrigation were assigned 0.02 cfs and 2 acre-feet per acre (Table 2b). The total quantity of surface water allocated by both rights and claims is 640.1 cfs; total quantity of ground water allocated by both rights and claims is 446 efs.

Table 2a Green-Duwamish Watershed Water Rights

Source	Qi (cfs)	Qa acre-feet)	Acres	Total Number of Rights
Ground	350.0	117,137	1,711	360
Surface	195.2	78,587*	5,543	500

*Total for rights issued since mid-1960's.

Table 2b Green-Duwamish Watershed Claims (estimated quantities)

Source	Qi (cfs)	Qa. (acre-feet):	Irrigated Acres	Total Number of Clams
Ground	96.0	7,299	2,513	2613
Surface	444.9	3,917	1,670	717

52 nonconsumptive surface water rights totaling 98.6 cfs have been issued for fish propagation, hydroelectric power generation, and recreation.

Of the water rights Ecology has issued in the Green-Duwamish watershed, the principal use is municipal-domestic consumption; 57 percent of surface water rights, and 76 percent of the ground water rights are allocated to municipalities (Figures 5 and 6). The largest municipal user is the City of Tacoma, which has a surface water permit for 100 cfs (Pipeline 5, priority date 1933) and a ground water permit for 62,500 gpm (139.3 cfs, priority date 1970). These two permits account for the increase in cumulative rights in those years shown in Figures 7 and 8. Tacoma's Pipeline 5 permit is above and beyond their 1971 water right claim for 400 cfs.

Figures 9 and 10 plot the cumulative instantaneous quantity as percentages of the total quantity against the cumulative number of rights expressed as percentages of total number of rights. This illustrates the fact that 10 percent of the surface water right holders account for 84 percent of the surface water allocated in the watershed, and 10 percent of the ground water right holders account for 78 percent of the ground water allocated in the watershed. These graphs are a bit deceptive, however, as all of the larger purveyors is the basin have multiple water rights, thus the percentage of water right holders using say 90 percent of the .water is far smaller than indicated.

Pending Applications

There are 54 ground water applications on file with Ecology in the Green-Duwamish watershed requesting a total of 54,410 gpm (121.2 cfs). Of these, 42 are for municipal or multiple domestic use. No estimate of annual quantity was made. Approximately 12 of the pending applications are for groundwater downstream of the Auburn gage, requesting a total of 34,000 gpm. There are eight surface water applications for a total of 6.3 cfs for the entire basin.

Big Soos Creek Subbasin Water Rights

The majority of water rights issued in the Soos Creek Subbasin are ground water rights for municipal use. Twelve ground water rights are for municipal use, accounting for 67 percent of the allocated instantaneous quantity (Qi) and 81 percent of the annual quantity. The City of Kent, Covington Water District, and King County Water District #111 are the area's largest water purveyors. No surface water rights have been issued since the early 1980's.

Due to upstream diversions before 1967, the useable period of record for streamflow data for Big Soos Creek extends from 1967 to present. The Qi for ground water allocated in the subbasin during this period has increased from 5.3 cfs to 40.8 cfs, and the annual quantity (Qa) grew from 1,412 acre-feet to 19,297 acre-feet. Ground and surface water rights and claims are tabulated in Tables 3a and 3b.

Currently, there are 30 applications for water rights for ground water in the Soos Creek Subbasin, totaling 40.9 cfs, an amount equal to that already allocated.

Table 3a Big Soos Creek Subbasin Water Rights

Source :	Qi (cfs)	Qa (acre -feet)	Irrigated Acres	Tots Number of :Rights.
Ground	40.8	19,297	369	99
Surface	6.1	891	103	89

*total for rights issued since mid-1960's

Table 3b Big Soos Creek Subbasin Claims (estimated quantities)

Source	Qi (cfs):	Qa (acre-feet)	Irrigated Acres	`Total Number of Claims
Ground	43.3 cfs	3,194	1,118	1, 374
Surface	21.2 cfs	357	309	296

Newaukum Creek Subbasin Water Rights

There are three ground water rights for municipal use in the Newaukum Creek Subbasin for the city of Enumclaw, representing 56 percent of the allocated Qi and 75 percent of the Qa. Enumclaw also holds two surface water certificates for 1.75 cfs. The remaining water rights in the subbasin are predominately for irrigation and small multiple domestic systems. Water rights and claims are tabulated in Tables 4a and 4b.

Table 4a Newaukum Creek Subbasin Water Rights

Source	Qi (cfs):	Qa (acre-feet)	Irrigated Acres	`Total Number of Claims
Ground	14.2	5,045	469	41
Surface	8.4	160*	663	36

*total for rights issued since mid-1960's

Table 4b Newaukum Creek Subbasin Claims (estimated quantities)

Source	Qi (cfs):	Qa (acre-feet)	Irrigated Acres	`Total Number of Claims
Ground	6.3	1,029	467	163
Surface	1.2	495	241	32

Minimum Flows

As a result of the Hansen Dam's completion in 1962, and Tacoma's request to the ACOE to store water for the purpose of additional municipal and industrial supply, a number of entities appealed to the State to establish instream flow restrictions. Of greatest concern in these appeals was the additional 100 cfs diversion proposed by the City of Tacoma for Pipeline 5, in addition to Tacoma's existing water supply diversion of up to 112 cfs.

The Green-Duwamish River Basin Instream Resources Protection Program document (Ecology 1980) discussed some of the issues regarding the establishment of instream flow restrictions for the basin. A minimum flow of 110 cfs at the Palmer gage was established by the ACOE, under Congressional authorization. Releases from the reservoir augment the natural summer low flow in the Green River in order to provide adequate flow for the fisheries resource. The Washington Department of Fish and Wildlife considered these flows inadequate for the protection of instream resources and requested supplemental releases above the 110 cfs minimum flow.

METRO commented that Green River flow releases were often insufficient to alleviate poor water quality conditions in the lower Duwamish River. They believed that 550 cfs at the Auburn gage would be necessary to achieve Ecology water quality standards by diluting pollutants and flushing out the intruding salt water wedge from Elliott Bay.

On June 6, 1980, Chapter 173-509 WAC established instream flow restrictions on the main stem Green River near Auburn (Gage 12113000) (Figure 13) and near Palmer (Gage 12106700) (Figure 13). The WAC states that if natural Green River flows fall below the one in ten-year Green River flow frequency, the Ecology director may determine it necessary to allow flows below the normal year (instream flow curve) flows. Tacoma's diversion of 112 cfs, based on their vested claim (water diverted before the 1917 Water Code) is not subject to Washington State's 1980 minimum instream flow restriction. The ACOE is required only to release 110 cfs from storage for instream flows during periods of very low natural flow. Beyond the flow restrictions on the main stem, all tributaries to the Green-Duwamish are closed to additional surface water withdrawals under Chapter 173-509 WAC.

Water Quality

As stated in the Draft Green-Duwamish Watershed Nonpoint Water Quality Early-Action Plan (King County, 1989b), "Water quality is closely tied to water quantity. Water quality is a significant factor in allocation decisions by water purveyors in that water supplies for municipal and industrial use (e.g., domestic consumption) must be of high quality. At the same time, management of water quality may depend in large part on the availability of large quantities of water to dilute pollutants and maintain proper water temperatures. "

Under the Federal Clean Water Act (Section 303[d]), Ecology prepares a biannual list for EPA of "troubled waters," rivers, lakes, estuaries, and coastal waters that exceed water quality standards. The majority of water quality problems on the main stem of the Green River appear to occur below the Auburn gage. According to the Section 303(d) list (Ecology 1994), these problems include numerous excursions beyond the Class A criteria for mercury, temperature, dissolved oxygen, and fecal coliform. The Duwamish River, which is classified as a Class B waterway, is also listed in the Section 303(d) list as having excursions for dissolved oxygen and fecal coliform. The list also cites excursions beyond criteria in sediment for copper, lead, zinc, polyaromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs).

Seattle METRO. monitors water quality sampling stations monthly throughout the Green-Duwamish Watershed (Figure 14). Three sampling stations (305, 307, and 309) monitor the Duwamish Estuary, while four sampling stations (3106, 311, A319 and B319) monitor the lower Green River. METRO sampling stations are also located on Newaukum Creek (0322), and in the Soos Creek basin (A320, C320, D320, and G320).

Waters within the three Duwamish estuary sampling stations are classified by the Washington Department of Ecology as Class B waters. The lower Green River and its tributaries are classified by the Department of Ecology as Class A waters. Class A waters can be used for water supply, stock watering, fish -and wildlife habitat and recreation. However, the Green River is also on the Washington Department of Ecology's 1994 list of "troubled waterbodies" for mercury, temperature, dissolved oxygen, and fecal coliform. This listing reflects the system-wide monitoring results that show that not all water quality standards are being met.

The lower Green River has good to excellent water quality according to Seattle METRO. Upstream sites are better quality than downstream ones. According to METRO (1989), "The temperature, fecal coliform, and pH levels always met the Ecology criteria for Class A waters at the two upstream sites (Stations A319 and B319). The dissolved oxygen (DO) levels at Stations 3106 and 311 were below the criterion on two of the routine sample dates, while the fecal coliform levels exceeded 200 org/100 ml in seven and five samples, respectively. These sites, except for Station 3106, met the fecal coliform criterion more often than most of the other sites sampled. " Since diversion of METRO's Renton Treatment Plant effluent in March 1987, the DO has increased and total-Phosphorous and ammonia have decreased (METRO, 1989).

The most significant water quality problem in the Soos Creek basin relates to elevated fecal coliform levels. According to the 1994 Section 303(d) list submitted by Ecology to EPA, a total of 73 excursions beyond the Class A fecal coliform criteria occurred at four Soos Creek stations between July 1987 and July 1991. Soos Creek is classified as a Class A stream segment by the state according to WAC 173-201 WAC. Livestock access to streams appears to be the primary cause of the high fecal coliform levels. The 303(d) list also indicates that two excursions beyond the mercury criteria occurred at one Soos Creek station between October 1989 and, January 1990. The 1990 Soos Creek Basin Plan discusses adverse effects on fish stocks specifically caused by nonpoint stormwater pollution. These problems include pollutants carried by stormwater runoff and increased water borne sediments in the basin's streams.

According to the Section 303(d) list (Ecology, 1994), four Newaukum Creek stations had a total of 119 excursions beyond the Class A fecal coliform criteria between July 1987 and July 1991. Again, livestock stream access appears to be the primary cause of these high levels. When compared with other King County monitored sites, the water appeared to be cooler and better oxygenated than most. However, nitrate and ammonia values were also higher, presumably due to dairy farming and cattle ranching upstream. The nutrient loading rate for nitrate and ammonia from Newaukum Creek to the Green River were the first and the third highest, respectively, for all the basins which METRO studied.

<u>Fisheries</u>

The 1980 Green-Duwamish River Basin IRPP document (Ecology, 1980) states that anadromous salmonids found in the Green River are chinook *(Oncorhynchus tshawytscha*), coho *(O. kisutch*), and chum *(O. keta)* salmon and steelhead trout (O. mykiss). Pink salmon were once abundant but have not been reported in recent years. Chum runs have declined, but a viable native population remains and is now being augmented by an enhancement program by the Muckleshoot Tribe. Figure 15 shows the major channels that have been identified at risk by the American Fisheries Society (AFS) or are listed as depressed by the Salmon and Steelhead Stock Inventory (SASSI).

The Washington. Department of Fisheries operates a large salmon hatchery near the mouth of Soos Creek. Annual returns of adult fish to the hatchery range from 12,000 to 14,000 for fall chinook salmon and 6,000 to 10,000 for coho salmon (Goldstein, 1982). Three to six thousand coho are released upstream to spawn naturally. In addition to supporting natural spawning and rearing, the upstream areas of the hatchery are utilized for rearing by hatchery fry that are planted throughout the basin.

Habitats found within the watershed vary considerably due to changes in channel gradients, stream morphology, and . current levels of commercial or domestic development. These habitats can be separated into 4 generalized river reaches:

1) Upper-Middle Green River
2) Lower Green River
3) Newaukum and Soos Creek Subbasins
4) the Duwamish Estuary

Fisheries habitat within the Upper-Middle Green River consist primarily of cascades and rapids confined in relatively narrow steep-sloped valleys. Substrates are dominated by boulders, rubble, and large cobbles. Tacoma's water diversion dam blocks all upstream migration of salmonids to a substantial part of the upper-middle Green River watershed. Presently, no spawning occurs upstream of the diversion dam, but juvenile salmonids are outplanted in tributaries upstream of HAH dam. Tributaries in the upper-middle Green River drainage provide little accessible habitat for anadromous salmonids (Grette and Salo, 1986).

The Lower Green River, below RM 40, takes on the characteristics of a large river. Stream gradients decrease, river widths increase and the river begins to meander through a broad glacially carved valley that has been filled with fluvial deposits. The lower Green River is diked or protected by revetments from RM 38 to the dredged portion of the Duwamish waterways (RM 5.2). Due to the artificial dikes and revetments, as well as increased development, riparian areas have suffered along the lower river. Tree growth is largely prohibited in some diked areas resulting in streambanks that provide little shade to the river. Although a substantial amount of spawning occurs in the main stem of the river from RM 26 (Kent area) to the Tacoma Diversion

Dam (RM 62), spawning activity is most intense between RM 32 (Auburn) and R.M 47. The River below Kent appears to be poorly utilized for salmonid spawning (METRO, 1989).

The two most important tributaries of the Green River enter in this lower section. Newaukum Creek enters the south bank at RM 40.7 and Big Soos Creek joins on the north bank at RM 33.7. Stream gradients are typically low, substrates are dominated by large gravels, and riparian areas are typically wooded or well vegetated except for areas of pastureland and some residential development (King County, 1990). There are significant runs of chinook and coho salmon, and steelhead trout throughout the Soos Creek subbasin. The stream is used for migration, spawning, and rearing. Significant runs of chum salmon occur in the lower reaches of Newaukum Creek, and coho salmon are found throughout the system. However, spawning substrate is the limiting factor on Newaukum Creek, as there is only a moderate amount of fine gravel. The lower reaches of the creek have been straightened and have limited quantities of riparian vegetation (King County, 1989a).

The Duwamish Estuary is defined for this report as the area from RM 12 to Elliott Bay. Fish habitat has been degraded in the Duwamish Estuary by extensive residential and commercial development. Riparian zones and adjacent lands are characterized by intensive commercial and industrial developments that are often built up to or directly over the surface of the water. River sediments are contaminated and the Duwamish is considered to be a major source of pollutants for Puget Sound (Harper-Owes 1983). The natural estuarine habitats in this area have been totally destroyed except for a remnant on Kellogg Island, which itself has been affected by disposal of dredge materials (Greite and Salo, 1986).

The Green-Duwamish River Basin IRPP report (Ecology, 1980) explains that intergravel egg development occurs over an 11-month period due to the overlapping spawning period of various species. High flows during the period of March through June apparently mark the peak of out-migration for all species, although several of these redistribute within the stream system throughout the year.

Adult salmonids migrate upstream through the Duwamish River throughout the year. Although the Pacific salmon species (chinook, chum, and coho) migrate upstream during late summer, fall, and early winter, steelhead trout migrate in both winter and summer runs. Timing of upstream migration of the Pacific salmon is largely controlled by rainfall, stream flow, and barometric pressure. Migrating salmon congregate near the mouth of the Duwamish River during July and August before migrating predominantly between September through January (Miller and Stauffer, 1967). Although dissolved oxygen values in the lower river have improved since discontinuation of the upstream wastewater discharge from the Renton treatment plant (METRO, 1990), levels as low as 3.1 mg/1 prior to diversion did not appear to hinder migration (Miller and Stauffer, 1967) .

Downstream migration by juvenile salmon and steelhead primarily occurs in late winter and early spring. Chum salmon out-migrate beginning in late February and both chinook and coho, begin in early April. Out-migration usually lasts through mid-July to early August for most species. Downstream migration by juvenile salmonids calls for spending more time in the lower Duwamish River than upstream migration. During this time, juveniles use the estuary to feed and physiologically adapt to marine salinities. Among numerous beneficial uses of the lower Duwamish River identified by METRO, use as habitat for out-migrating juvenile salmonids was listed as the most important (Harper-Owes, 1983).

Two of the most prominent studies regarding the health of fish stocks in Washington State are: 1) A paper published in the March-April 1991 issue of Fisheries entitled, "Pacific salmon at the crossroads: Stocks at risk from California, Oregon, Idaho, and Washington" and 2) The "1992 Salmon and Steelhead Stock Inventory" (SASSI) published in March 1993. The former paper attempted to assess the future risk of extinction for selected stocks. That report described the status of chum salmon stocks only for the Green/Duwamish Rivers, which it described as being at high risk of extinction. The SASSI report examined the current status of salmon and steelhead stocks for Washington State. That report described chinook, coho, and steelhead stocks on the Duwamish and Green Rivers as healthy, and chum status as unknown.

Caldwell and Hirschey (1989) conducted a study of the Green River using the Instream Flow Incremental Methodology. Their report concluded that , "There is no one flow at which habitat for fish is optimum. The different fish species and lifestages exist simultaneously in the river, and each has a different optimum flow requirement. Providing an optimum habitat flow for one lifestage will usually result in the habitat loss for another lifestage. Peak habitat flow does not necessarily equate with peak fish production. Flows higher than peak habitat flows are needed for juvenile fish at certain times of the year to maintain existing production levels."

Mathews and Olson (1980) studied factors which can affect Puget Sound coho salmon runs. They concluded that summer streamflow was an important determinant of Puget Sound coho run strength since 1952, apparently due to' its affect on zero-age salmon. They also reference earlier studies which indicate a relationship between rearing flows an coho run strength beginning in 1935. Mathews and Olson's report suggests survival of hatchery coho may be positively dependent upon the same environmental conditions that affect stream-reared coho. The IRPP document also presents data which indicate a positive relationship between the magnitude of the lowest recorded flow and the steelhead production for each year, but results are not conclusive.

Adverse conditions affecting the migration of fish include poor water quality, high stream temperatures, physical barriers, the destruction of spawning habitat, and detrimentally low streamflows. A water temperature investigation conducted by Caldwell (1992) concluded that portions of the middle-lower Green (RM 13 to RM 45) frequently exceeded Washington State water quality standards for temperature, and that salmonid rearing capabilities were adversely affected. The report indicates a potential for blockage or delay of upstream migration of fish during August and hypothesizes that warm summer minimum temperatures are the result of several factors including limited ground water inflow, increased impervious surfaces, and higher daily temperatures.

STREAMFLOW STATUS

Objectives of Analysis

There have been significant changes in the Green-Duwamish watershed since collection of flow data began decades ago. As previously discussed, the demands on surface and ground water use has grown rapidly over the past 20 to 30 years. Population growth and urbanization in the watershed has increased impervious land areas thereby reducing ground water recharge (King County, 1990; Carlson, 1994). In addition, there is evidence that annual precipitation has been declining over the last few decades. Each of these factors can affect the streamflow status of the river, most notably by reducing summer low flows.

To better understand the impacts of changing conditions in the watershed on streamflow status, and to assess potential cause and effect mechanisms, flow and precipitation data from the watershed were analyzed for trends. Flow data from USGS gages located on the Green River near Auburn and Palmer, on Soos Creek above the hatchery, and on Newaukum Creek were evaluated for low flow trends. In addition, the Auburn and Palmer gage data were evaluated for flow exceedence values.

In the analyses presented below we used all available records which did not include unusual or atypical flow conditions. For the Auburn and Palmer gages, we used data starting in 1961, since the Hansen Dam began filling in December of that year. For the Soos Creek gage, we used data collected starting in 1968, since water was diverted upstream of the gage by the hatchery during the previous year. For the Newaukum Creek gage, we used data collected starting in 1953, since there was a break in data prior to that time.

Flow Exceedence

Flow exceedence curves were developed for the Auburn and Palmer gage stations (Figures 16 and 17). More than 30 years of flow data were used in calculating the monthly flow curves for 90, 50 and 10 percent exceedence probabilities. The 90 percent curve represents low flow conditions since flows at any time during a given year have a 90 percent probability of exceeding the plotted values. The 50 percent curve shows the median flow values and approximates normal flow conditions throughout the year.

For the Auburn gage station, the 90 percent exceedence curve is above the established instream flow requirements December through mid-May but drops below the instream flow requirements for the remainder of the year (Figure 16). Based on the 90 percent exceedence curve, there is a 10 percent probability that the lowest flow period during any given summer will begin approximately two months earlier and end approximately one month later than allowed by established instream flow requirements. The 50 percent exceedence curve indicates that normal conditions flows at the Auburn gage are well above established instream flows except during seven weeks of the summer.

For the Palmer gage station, the 90 percent exceedence curve is above the normal year instream flow requirement early November through mid-May but drops below the instream flow requirements for the remainder of the year (Figure 17). Thus, there is a 10 percent probability that the lowest flow period during any given summer will begin at least five weeks earlier and end about two weeks later than allowed by the established instream flow requirements during normal flow years. The 90 percent exceedence curve is above the critical year instream flow line early November through mid-May but drops below the instream flow requirements for the remainder of the year. The 50 percent exceedence curve indicates that under normal conditions, flows at the Palmer gage are above normal year instream flow requirements except during four weeks of the summer.

Low Flows

Low. flows in the river were evaluated by calculating 7-day low flow values for each year. The 7-day flow duration is conventionally used in evaluating low flows because shorter flow durations have much greater variability.

When plotted over time, there are no clear trends in average 7-day low flows at the Auburn gage station (Figure 18), nor at the Palmer gage station (Figure 19). However, declining trends in 7-day low flows were detected in Soos Creek (Figure 20) and Newaukum Creek (Figure 21), both of which join the Green River between Palmer and Auburn. Carlson (1994) estimated a 5 cfs decline in mean annual 7-day low flows in Soos Creek over the past two decades.

The 7-day low flow data for the Auburn and Palmer gages also illustrate that in most years instream flow requirements are not met during low flow periods (Figure 18 and 19). At the Auburn gage station there were only three years between 1963 and 1993 when the average 7-day low flow met instream flow requirements (Figure 18). At the Palmer gage station there were only four years between 1964 and 1993 when the average 7-day low flow met instream flow requirements (Figure 19). The data in Figure 19 further indicate that the minimum 110 cfs flow at the Palmer gage, established under Congressional authorization, was not maintained by the COE for periods during nine of the past 29 years.

Additional duration analyses, not presented here, were conducted for a 60-day low flow period for both the Auburn and Palmer gages and compared to established instream flow requirements. For the 60-day period, established instream flow requirements were not met at either gage location 50 percent of the time.

The total number of days that Chapter 173-509 WAC instream flow requirements were not met were calculated on an annual basis and also for seasonal low flow periods. Instream flow requirements were not met an average of 103, 100, and 82 days, compared with Auburn normal year, Palmer normal year, and Palmer critical year instream flows, respectively. Based on linear regression analyses of the data since 1980, there is a weak correlation between years and the number of days that minimum flows were not met (Figures 22 through 24).
Based on the Auburn gage trend line, the total annual number of days instream flow requirements were not met increased from about 75 to 135 days during the period 1980-1992 (Figure 22). The large difference between the annual and seasonal flow values suggests that instream flows were not met for a significant number of days outside the low flow period.

Based on the Palmer gage trend line, the total annual number of days normal instream flow requirements were not met increased from about 78 to 123 days during the period 1980-1992 (Figure 23). As with the Auburn data, the large difference between the annual and seasonal flow values suggests that instream flows were not met for a significant number of days outside the low flow period. During the same time period, the total annual number of days critical instream flow requirements were not met increased from about 65 to 110 days at the Palmer gage station (Figure 24). The similarity between the annual and seasonal flow values suggests that there were relatively few days when instream flows were not met outside the low flow period. Since 1980, when the critical instream flow requirements were adopted, Ecology has never officially declared a critical. flow year for the Palmer gage.

Precipitation

Palmer weather station precipitation was compared with mean annual flow and low mean monthly flow for the Soos Creek and Newaukum Creek gages (Figures 25 and 26). The units of rainfall were converted from inches to cfs by multiplying the rainfall amount by the basin area and dividing by the number of seconds in a year. There is an apparent declining trend in rainfall, which amounts to a 6 percent decline in Soos Creek and a 16 percent decline in Newaukum Creek for the time periods evaluated.

Interpretation of Streamflow Status

It is evident from the preceding analyses that there have been declines in summer low flows over the past decades. Based on linear regression analyses of the data, there is a correlation between years and the declines in precipitation, mean annual flows, and summer low flows for both Soos Creek and Newaukum Creek. For Soos Creek, we estimate a 14 percent decline in mean annual flow and a 33 percent decline in low flows during the period from 1967 to 1992 (Figure 27). During that same time period, rainfall declined 6 percent. For Newaukum Creek, we estimate a 20 percent decline in mean annual flows and a 24 percent decline in low flows during the period from 1953 to 1992, with a corresponding 16 percent decline in rainfall (Figure 28). The differences in percent rainfall decline are due to different time periods.

Comparing the relative decline in precipitation to the declines in mean annual flows and low flows suggests that declining precipitation is not the only cause of declining flows. After conducting a similar analysis on two streams in addition to Soos Creek and Newaukum Creek, Carlson (1994) concluded that declining flows in Soos Creek from 1967-1992 were not caused primarily by declining precipitation, but rather by ground water withdrawals.

Increases in impervious surface areas in the watershed resulting from urbanization have most likely also reduced summer flows. Projections for urbanization in the watershed suggest that impacts from additional impervious areas will be of growing concern. King County Surface Water Management Division has estimated a three-fold increase in impervious area from 1985 to future high-density development (King County, 1990).

SUMMARY AND CONCLUSIONS

Maintaining minimum instream flows is a key factor in managing water quality in the Green-Duwamish River system. A continued supply of clean water is needed to dilute pollutants in the rivers and to hold back saltwater intrusion at the mouth of the Duwamish. Instream flows are also important for protection of fish and aquatic habitat. Intergravel egg development occurs over an 11-month period due to the overlapping spawning period of various species, and low flow periods exacerbate temperature stress and other water quality problems. Although annual high flows from rain and snowmelt runoff between March and June mark the peak of out-migration for all species, several species redistribute within the stream system throughout the year.

Instream flows are monitored and controlled at several points in the watershed. The ACOE monitors precipitation, snowpack, and reservoir inflow at Hansen Dam to determine optimal reservoir levels and downstream releases. Downstream of the dam, the City of Tacoma removes up to 112 cfs under its water right claim. Below these points, the Palmer and Auburn gages have minimum instream flows established in Chapter 173-509 WAC.

When plotted over time, there are no clear trends in average 7-day low flows at the Palmer and Auburn gages. However, declining trends in 7-day low flows were detected in Soos Creek and Newaukum Creek, both of which join the Green River between Palmer and Auburn. The total number of days that Chapter 173-509 WAC instream flow requirements were not met were calculated on an annual basis and also for seasonal low flow periods. Instream flow requirements were not met an average of 103, 100, and 82 days, compared with Auburn normal year, Palmer normal year, and Palmer critical year instream flows, respectively. Based on linear regression analyses of the data since 1980, there is a weak correlation between years and the number of days that minimum flows were not met.

Based on the Palmer gage trend line, the total annual number of days that the normal. instream flow requirements were not met increased from about 78 to 123 days during the. period from 1980 to 1992. The Auburn gage trend line indicates that the total annual number of days that the instream flow requirements were not met increased from about 75 to 135 days during the period from 1980 to 1992. These analyses indicate that instream flows were not met for a significant number of days outside the low flow period.

The Hansen Dam and the City of Tacoma Diversion Dam have tremendous impacts on mainstem Green River flows and are required to leave 110 cfs instream, as measured at the Palmer gage. This amount is significantly less than that required by Chapter 173509 WAC. The City of Tacoma has yet to develop an additional 100 cfs authorized under an Ecology permit issued in 1985. If perfected, this water will be subject to Chapter 173-509 WAC, and the quantity taken should only be that above the established minimum instream flows. Thus, the use of additional water will likely require increased storage behind the Hansen Dam, in order to increase flow above the current 110 cfs target low flow rate. The ACOE has considered the potential need for operational modifications, however it appears unlikely that these will occur in the near future. Currently, the ACOE works in cooperation with Ecology, the City of Tacoma, the Muckleshoot Tribe, and the Department of Fisheries and Wildlife to balance flow with competing needs.

Chapter 509-030 WAC requires that diversions subject to regulation by the Palmer gage be discontinued when Green River flows fall below the critical year instream flows and that diversions subject to regulation by the Auburn gage be discontinued when Green River flows fall below normal year instream flows. The WAC also states that, "Future ground water withdrawal permits will not be affected by this chapter unless such withdrawal would clearly have an adverse impact upon the surface water system contrary to the intent and objectives of this chapter."

Thus, for the wells in the watershed where there is a clear relationship between ground water pumping and surface water flows, Ecology has a mandate to restrict ground water pumping. This need is most apparent in the shallower aquifers. For some of the deeper aquifers, however, implementation of the WAC is more complex as the effects will be stretched out over a longer period of time and will be difficult to detect. It is impossible to halt the impacts of deeper wells only during those periods when instream flows are not met. Furthermore, much of the ground water withdrawn in the watershed is used by municipalities, for which issuing interruptable rights is often unacceptable.

Soos Creek, Newaukum Creek, and all other tributaries of the Green River have been closed to further appropriations since 1980 per Chapter 173-509 WAC. Nonetheless, declining trends in the average 7-day low flows were detected in both Soos and Newaukum Creeks for the last 26 and 40 years, respectively. The most likely causes for the flow declines in both these basins include decreased precipitation, increased ground water development, and an increased percentage of impervious surfaces. Data from the SeaTac and Tacoma weather stations indicate that precipitation was generally higher than average during the mid-1940s through mid-1970s, and lower than average since then, in direct relation to the recorded Soos Creek streamflow declines.

Based on information contained in the GWMP (SKCGWAC, 1989) and several studies conducted by the USGS, it also is apparent that ground water development in the Covington Upland has impacted Soos Creek flows. This is most obvious for the upper three or four aquifers, but also may be true for the deeper two. Furthermore, the USGS work suggests that ground water from the deeper aquifers discharges to regional drainage features including both the Green River and the Cedar River (WRIA 8). The Cedar River has instream flows established at Renton, per Chapter 173-508 WAC. None of these conclusions preclude the possibility that pumping from the deeper aquifers may lead to reduced Soos Creek flows.

In addition to the declining precipitation trends and increasing ground water withdrawals, increasing impervious surface areas within the watershed has led to decreased summer instream flows. The King County Surface Water Management Division has estimated a three-fold increase in the impervious area from 1985 to future high-density development and has observed an increase in stormwater flows (King County, 1990). Increases in impervious surfaces and stormwater flows have decreased aquifer recharge.

A simple method was used to evaluate the dominance of precipitation in controlling the downward flow trends in both Soos and Newaukum Creeks. Figure 27 indicates that from 1967 to 1992, Soos Creek mean annual flow decreased about 14 percent and low mean monthly, flow decreased about 33 percent, while Palmer precipitation decreased only about 5 percent. Conversely, for Newaukum Creek between 1953 and 1992, mean annual flow decreased about 20 percent, low mean monthly flow decreased about 24 percent, and Palmer precipitation decreased about 16 percent. This implies that while declines on the much less disturbed Newaukum Creek system were relatively similar, the summer flow declines were significantly greater for the more developed Soos Creek Subbasin. Consequently, the Soos Creek flow declines cannot be attributed to a decline in precipitation alone, and both the removal of ground water by pumping and the paving of surfaces are likely causes for summer flow declines: Additional ground water pumping from the closed Soos Creek Subbasin's upper three or four aquifers likely will result in additional surface water flow declines.

As pumping from the Soos Creek basin's deeper aquifers may produce a relatively small impact on Soos Creek flows, it is useful to quantify the amount of water that may be available from these aquifers. Based on USGS modeling of the Covington Upland, the average recharge available to the deeper system appears to be about two inches per year. Distributed over the basin's 72 square-mile (46,080 acre) size, this suggests that recharge to the deeper aquifers is about 7,680 acre-feet per year (af/yi). As only a portion of this recharge is available for use, it is possible that only about half that or about 3,840 of/yr of that may be available.

This initial assessment did not reconcile actual water use with allocated water rights arid claims. The amount of water allocated, however, has risen dramatically with increasing development. In the Soos Creek Subbasin alone, the allocations of ground water have risen from 5.3 to 40.8 cfs (Qi) and from 1,412 to 19,297 acre-feet from 1967 to 1994. Carlson (1994) compared the potential safe yield and water use within the Soos Creek Subbasin. She concluded that the hypothetical ground water yield of the subbasin (assuming 30 percent of recharge is available) is less than the quantity of water already allocated through ground water and spring rights and exempt well use. Water right claims increase this difference significantly.

There are 54 ground water applications on file with Ecology in the entire Green-Duwamish Watershed requesting a total of 54,410 gpm (121.2 cfs). Of these, 18 are for 1,000 gpm or more. There are eight surface water applications for the entire watershed for a total of 6.3 cfs. Currently, there are 30 applications for water rights for ground water in the Soos Creek Subbasin, totaling 18,300 gpm, an amount equal to that already allocated.

RECOMMENDATIONS

This initial watershed assessment relied on existing information. There were an abundance of reports on the study area, but there were some areas where data were lacking. The following recommendations call for additional information which will be helpful if a more comprehensive watershed assessment is conducted in the future.

- An active water use and water level monitoring program should be established for all major users of ground water within the watershed and a government agency made responsible for maintaining a data. base. These pumping wells should be equipped with a calibrated totaling-flow meter or equivalent, and the meters read at least monthly. Static water levels should also be measured in these wells at least monthly. This monitoring program should be coordinated with the South King County Ground Water Management Plan which has a partial database for some of these wells.
- All currently active weather stations and USGS gages should continue to be monitored.
- Crisp Creek should be included in decisions for the Soos Creek Subbasin. The Crisp Creek Subbasin is small and surrounded on three sides by the Soos Creek basin, and Crisp Creek serves as the sole source for the Muckleshoot Fish hatchery.
- More study should be directed toward the cause of declining flows on Soos Creek and Newaukum Creek. • Actual water use within the basin should be determined.
- The current area of impervious surfaces within the watershed should be estimated, so that a comparison can be made to 1985 levels.

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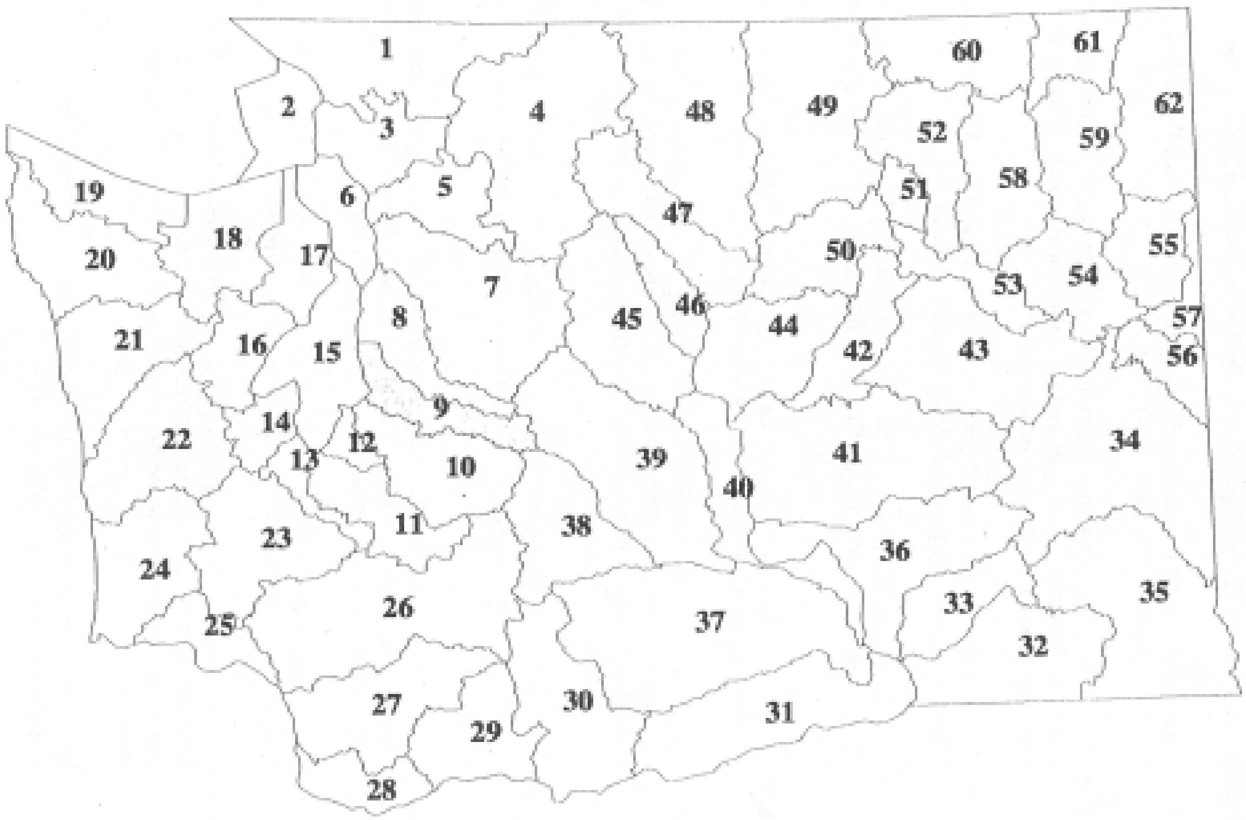
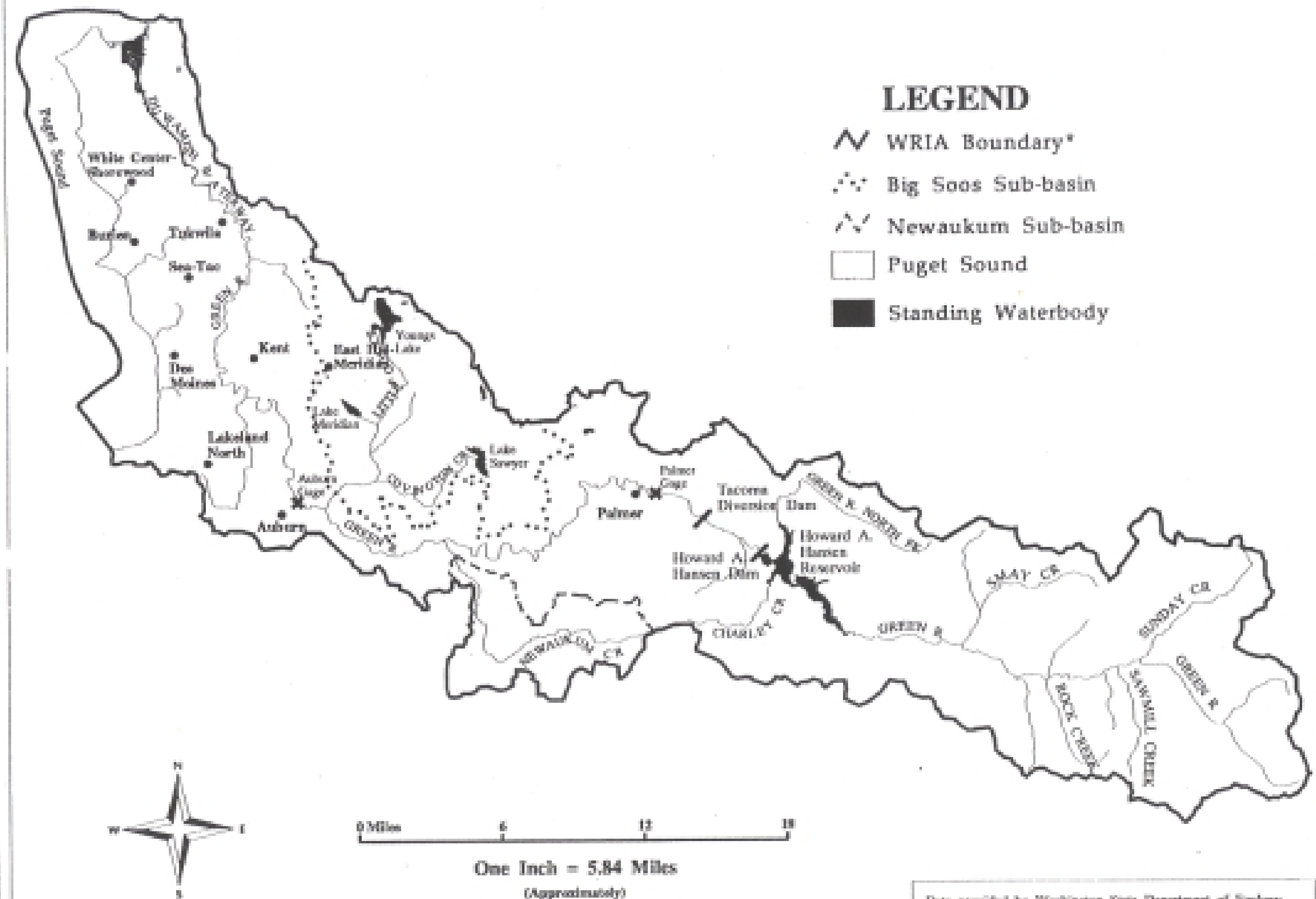
Washington Department of Ecology (Ecology). 1994. 1994 Section 303(d) List, Department of Ecology, Olympia, WA.

Figure 1: Water Resource Inventory Area (WRIA) Locator Map



WRIA 9 - GREEN-DUWAMISH WATERSHED

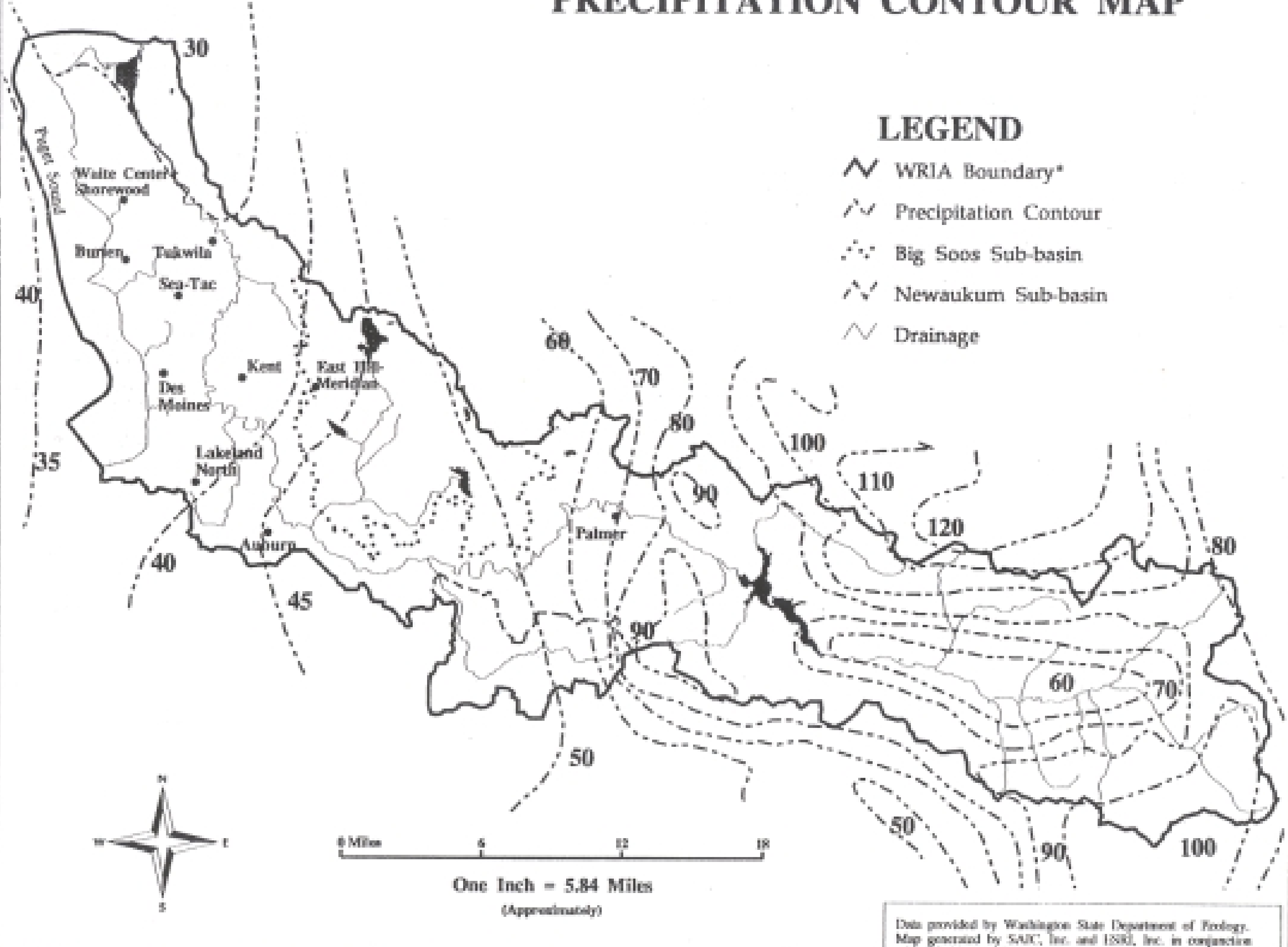
Figure 2 - WRIA 9: GREEN-DUWAMISH WATERSHED



Data provided by Washington State Department of Ecology. Map generated by SAIC, Inc. and ESRI, Inc. in conjunction with Washington State Department of Ecology. January 1995.

*WRIA Boundary is also outer boundary for sub-basins.

Figure 3 - WRIA 9: GREEN-DUWAMISH WATERSHED PRECIPITATION CONTOUR MAP



*WRIA Boundary is also outer boundary for sub-basins.

FIGURE 4 - MOVING 3-YEAR AVERAGES OF PRECIPITATION AT THE PALMER AND SEATAC WEATHER STATIONS

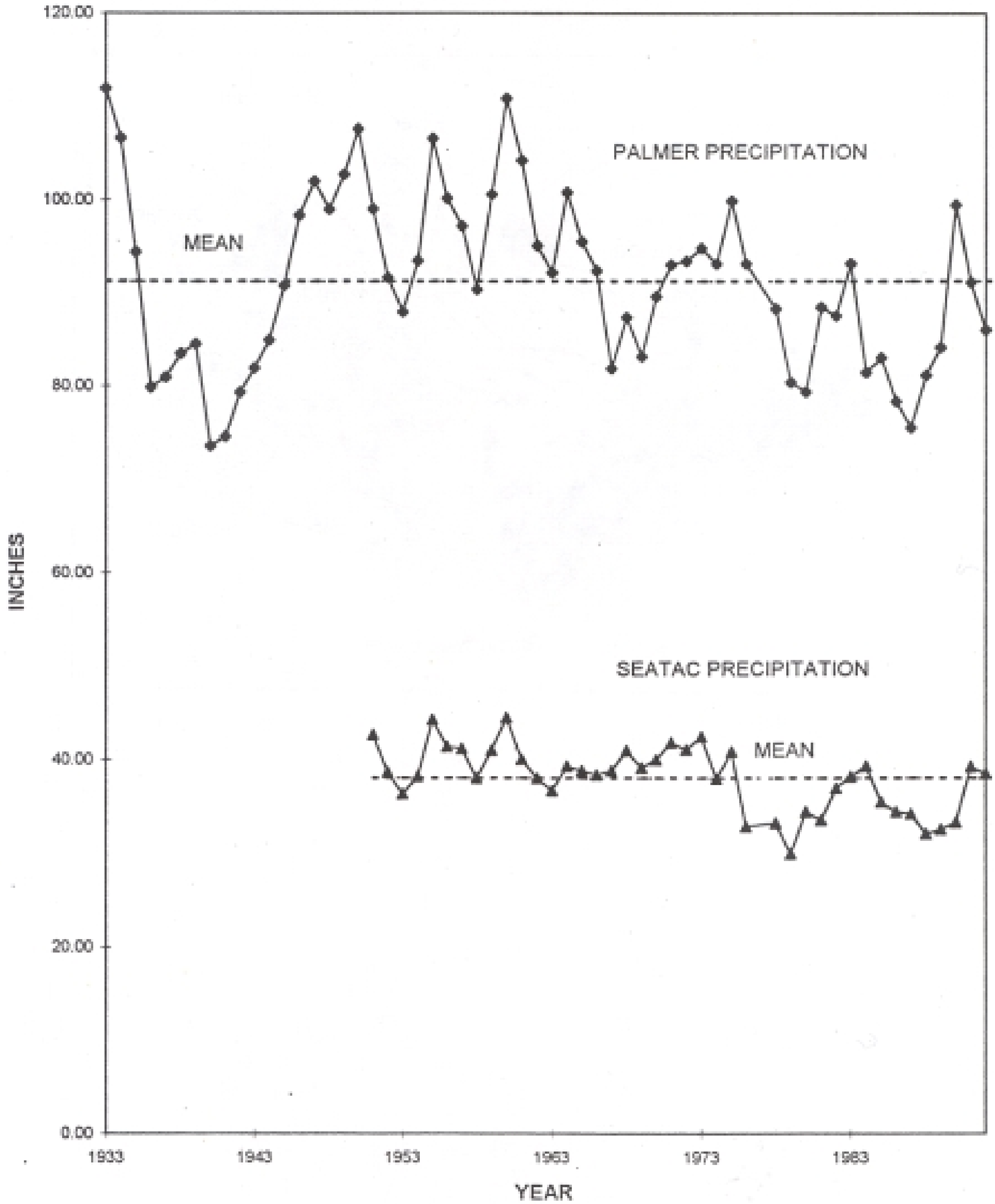
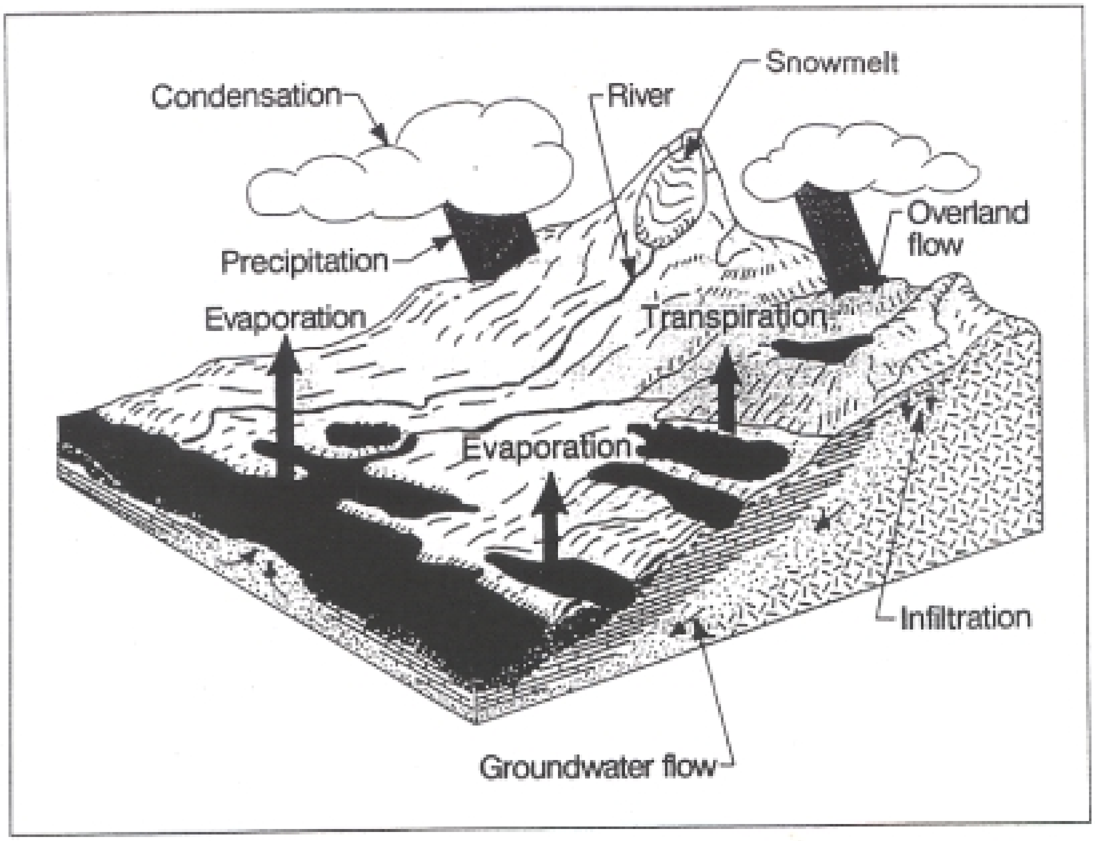
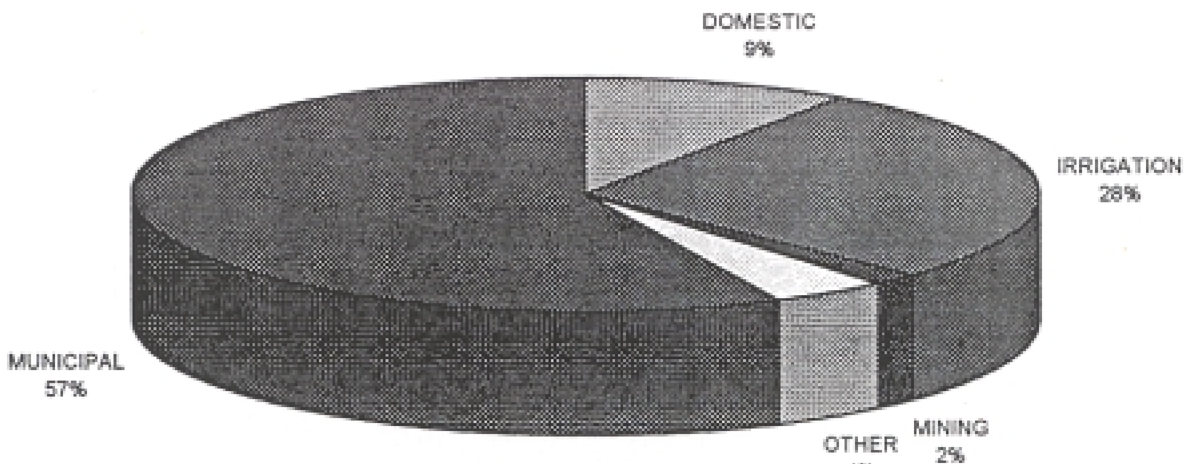


Figure 5 - The Hydrologic Cycle



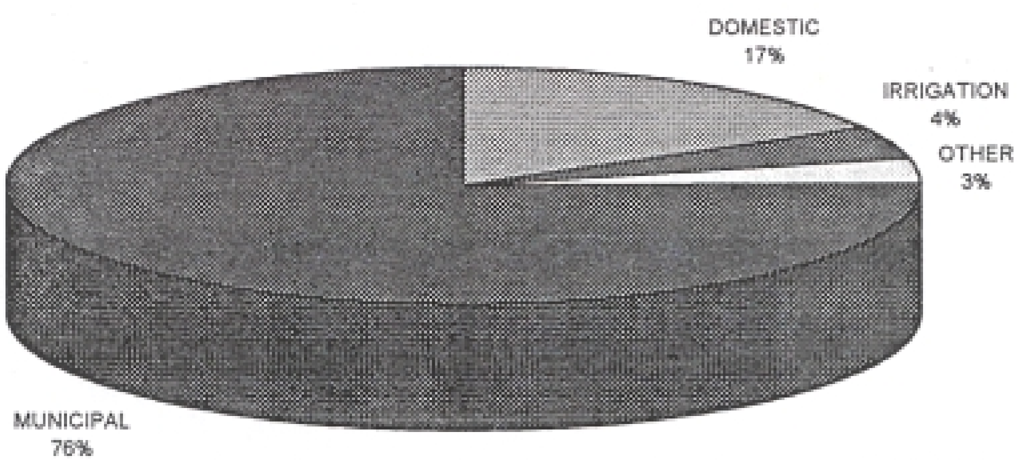
Source: Driscoll (1986)

FIGURE 6 - GREEN-DUWAMISH WATERSHED SURFACE WATER RIGHTS PRIMARY PURPOSE OF USE AS A PERCENTAGE OF TOTAL ALLOCATION



Out of a total allocated quantity of 195.2 CFS

FIGURE 7 - GREEN-DUWAMISH WATERSHED GROUND WATER RIGHTS PRIMARY PURPOSE OF USE AS A PERCENTAGE OF TOTAL ALLOCATION



Out of a total allocated quantity of 350 CFS

FIGURE 8 - GREEN-DUWAMISH WATERSHED
CUMULATIVE GROWTH IN SURFACE WATER RIGHTS

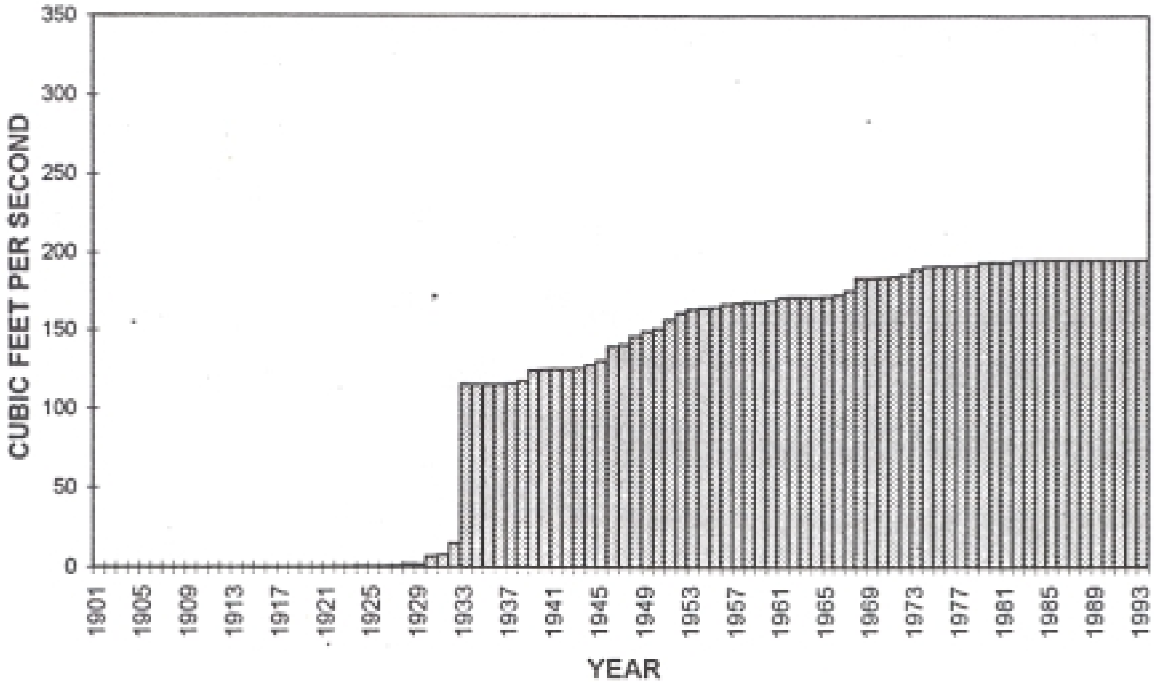


FIGURE 9 - GREEN-DUWAMISH WATERSHED
CUMULATIVE GROWTH IN GROUND WATER RIGHTS

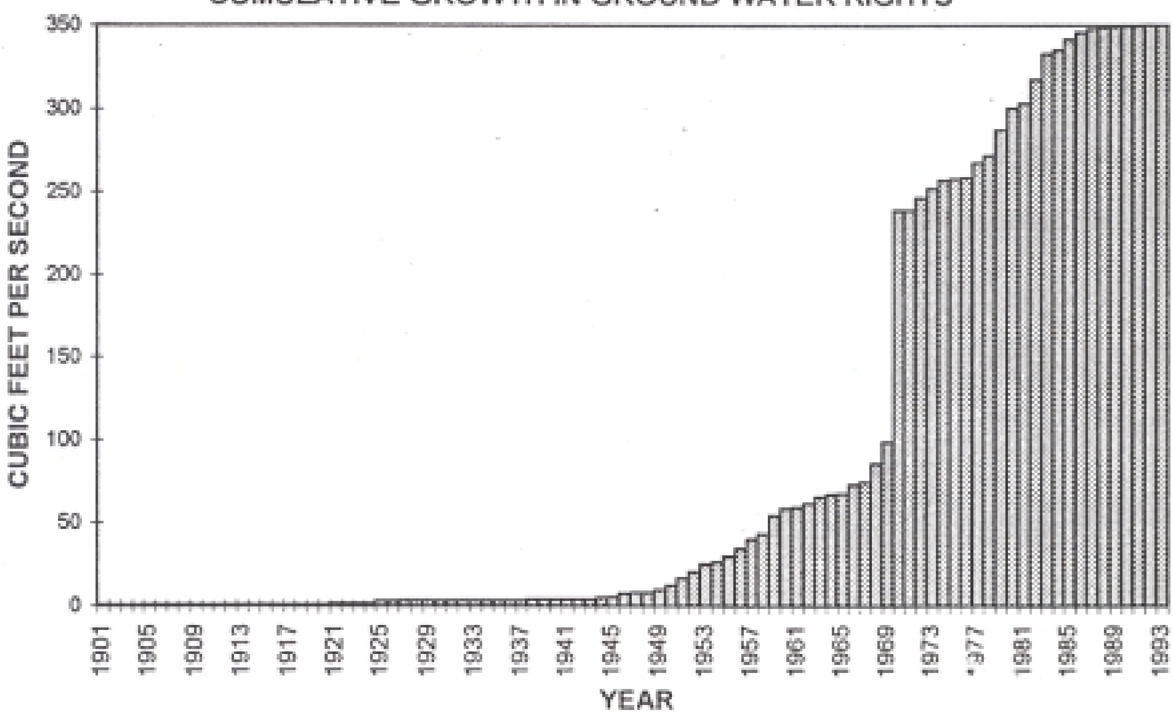


FIGURE 10 - GREEN-DUWAMISH WATERSHED SURFACE WATER VOLUME VS. NUMBER OF WATER RIGHTS

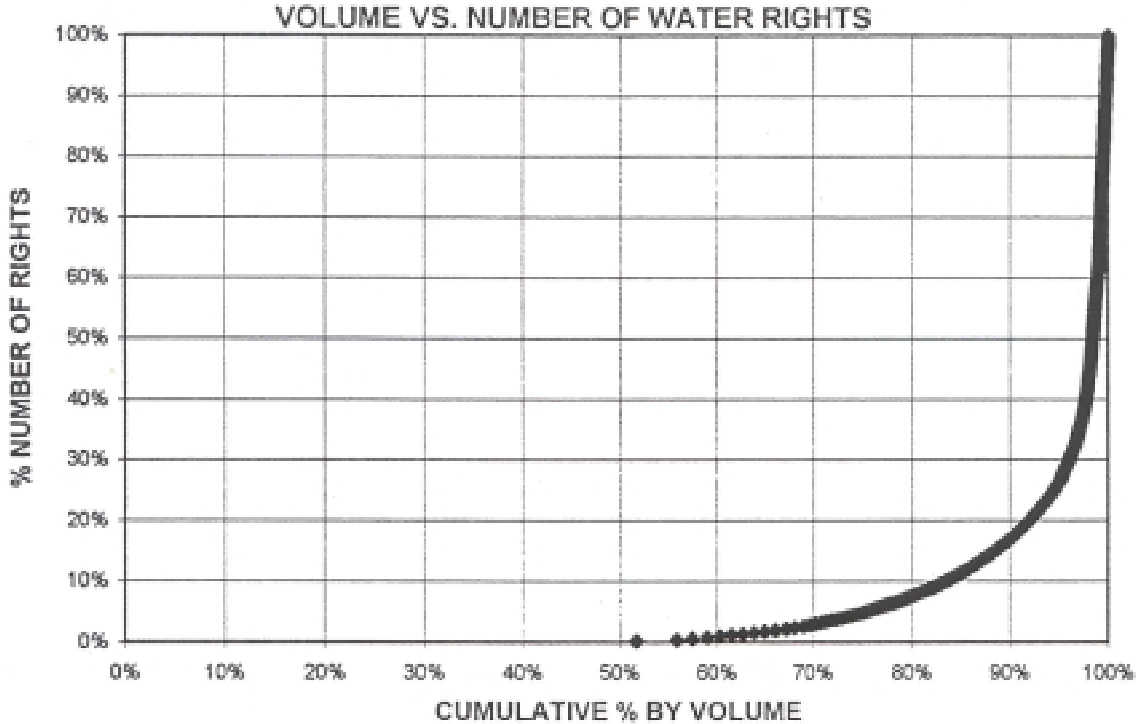
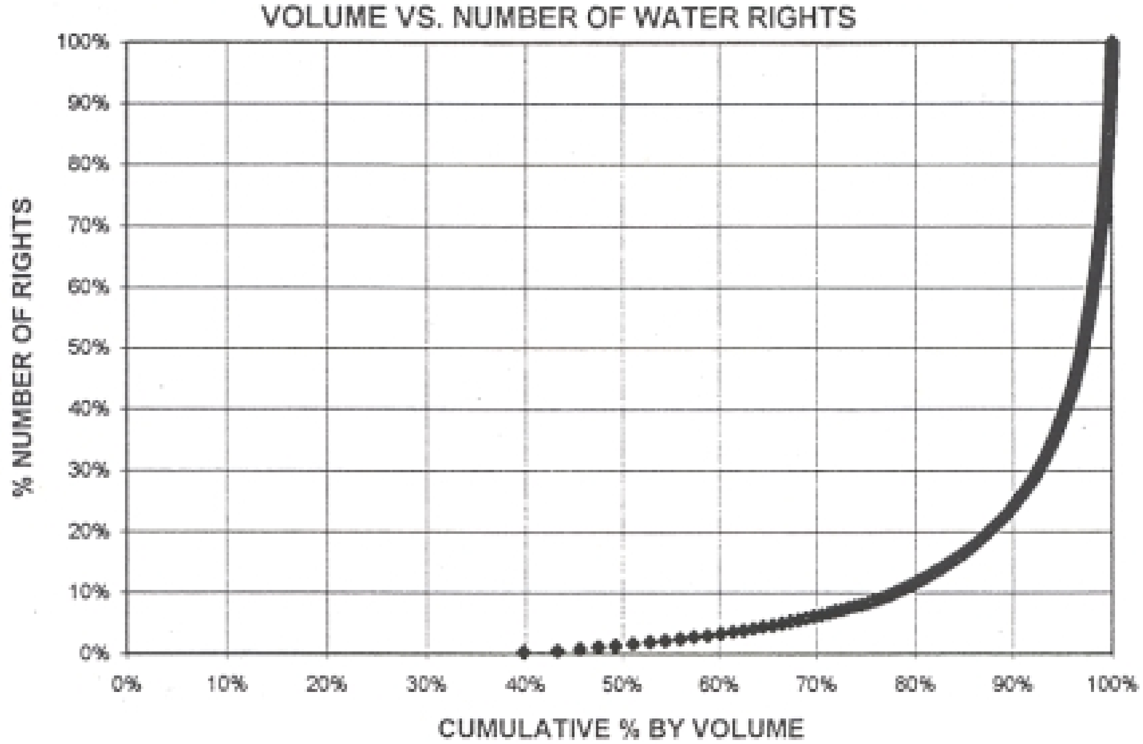


FIGURE 11 - GREEN-DUWAMISH WATERSHED - GROUND WATER VOLUME VS. NUMBER OF WATER RIGHTS



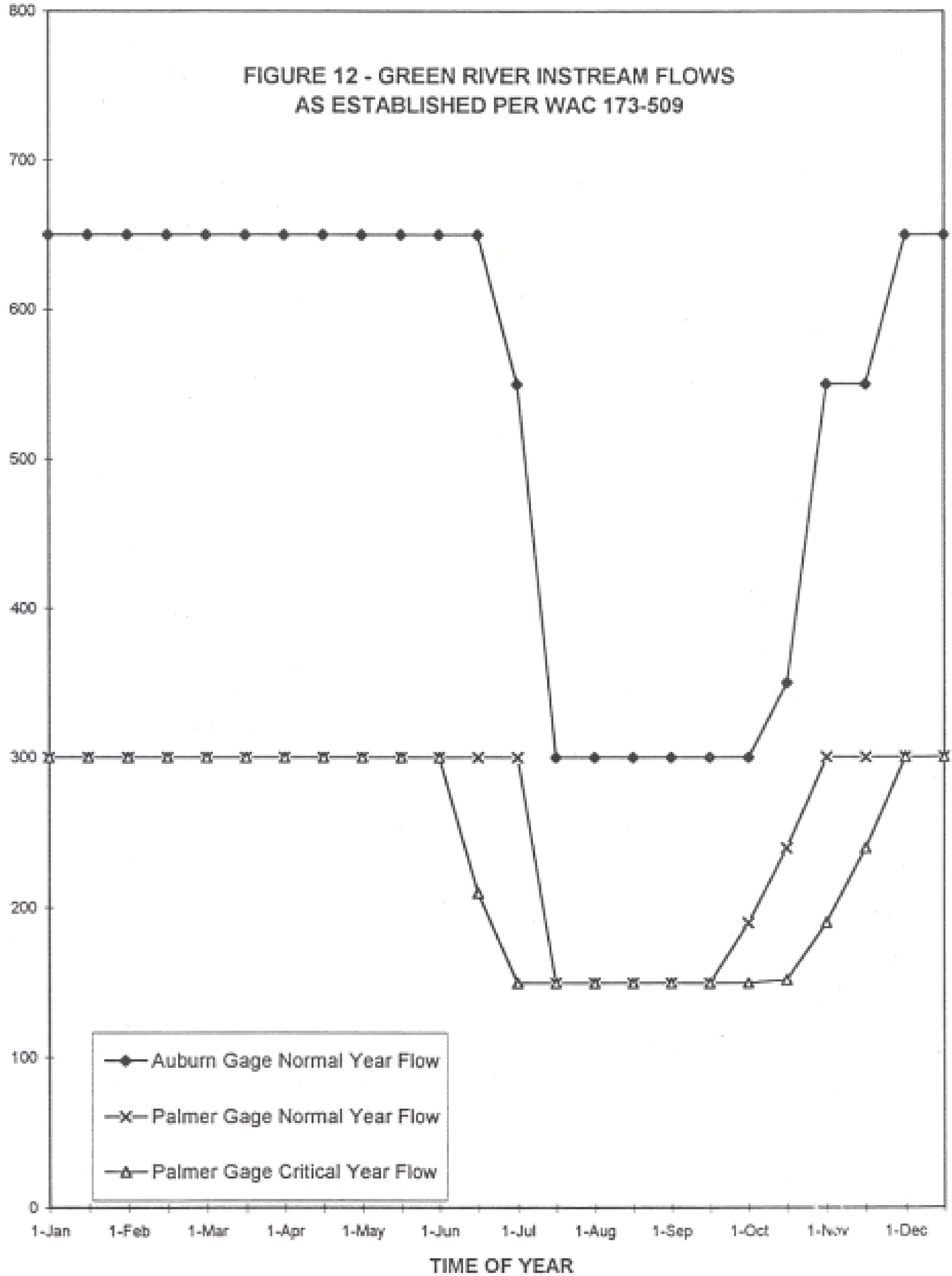
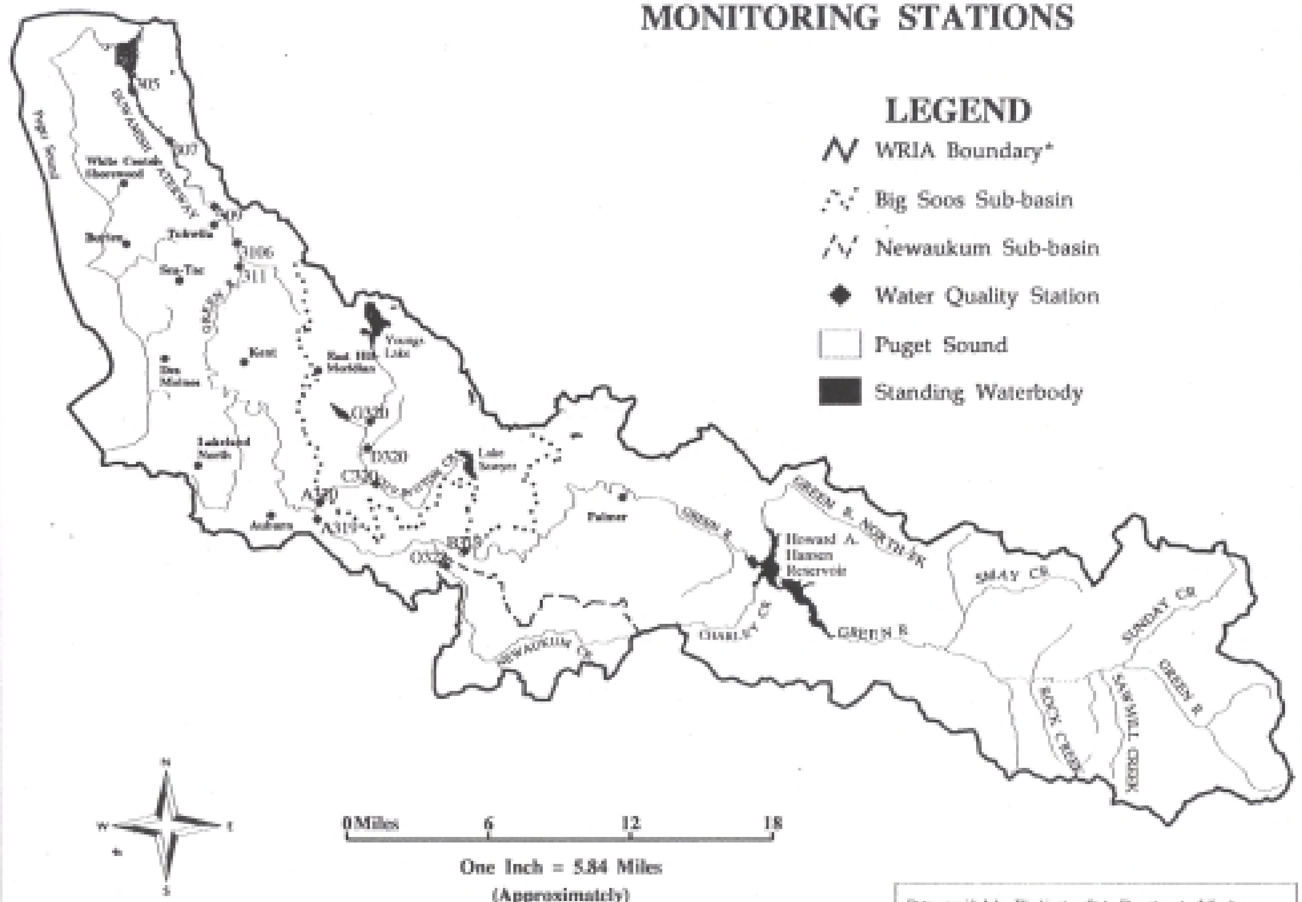


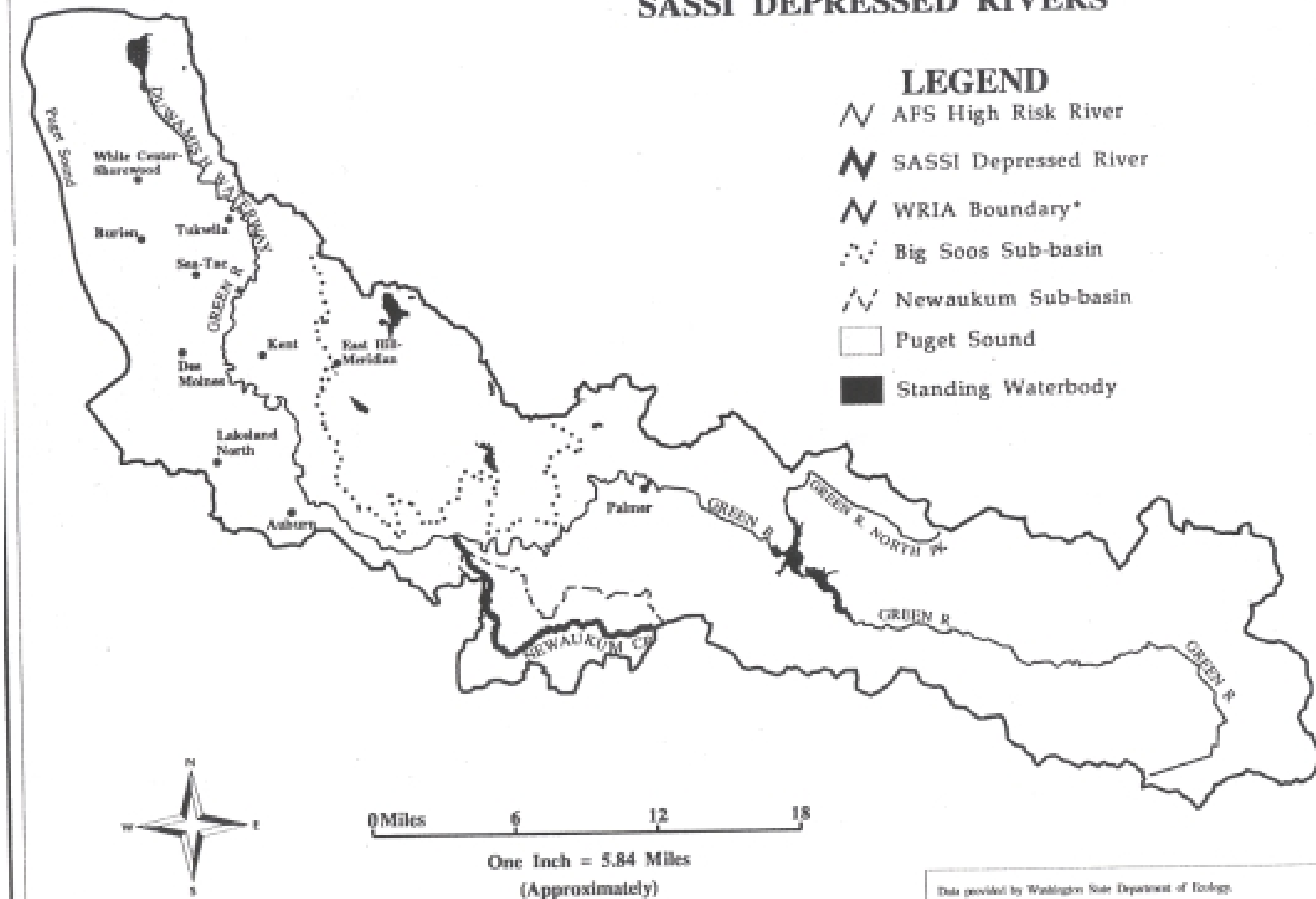
FIGURE 12 - GREEN RIVER INSTREAM FLOWS
AS ESTABLISHED PER WAC 173-509
800
700
600
500
400
300
200
100
0
Auburn Gage Normal Year Flow
Palmer Gage Normal Year Flow
Palmer Gage Critical Year Flow
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
TIME OF YEAR

Figure 13 - WRIA 9: GREEN-DUWAMISH WATERSHED
METRO WATER QUALITY MONITORING STATIONS



*WRIA Boundary is also outer boundary for sub-basins.

Figure 14 - WRIA 9: GREEN-DUWAMISH WATERSHED
AFS RISK AND SASSI DEPRESSED RIVERS



Data provided by Washington State Department of Ecology. Map generated by SAIC, Inc. and ESRI, Inc. in conjunction with Washington State Department of Ecology. January 1995.

*WRIA Boundary is also outer boundary for sub-basins.

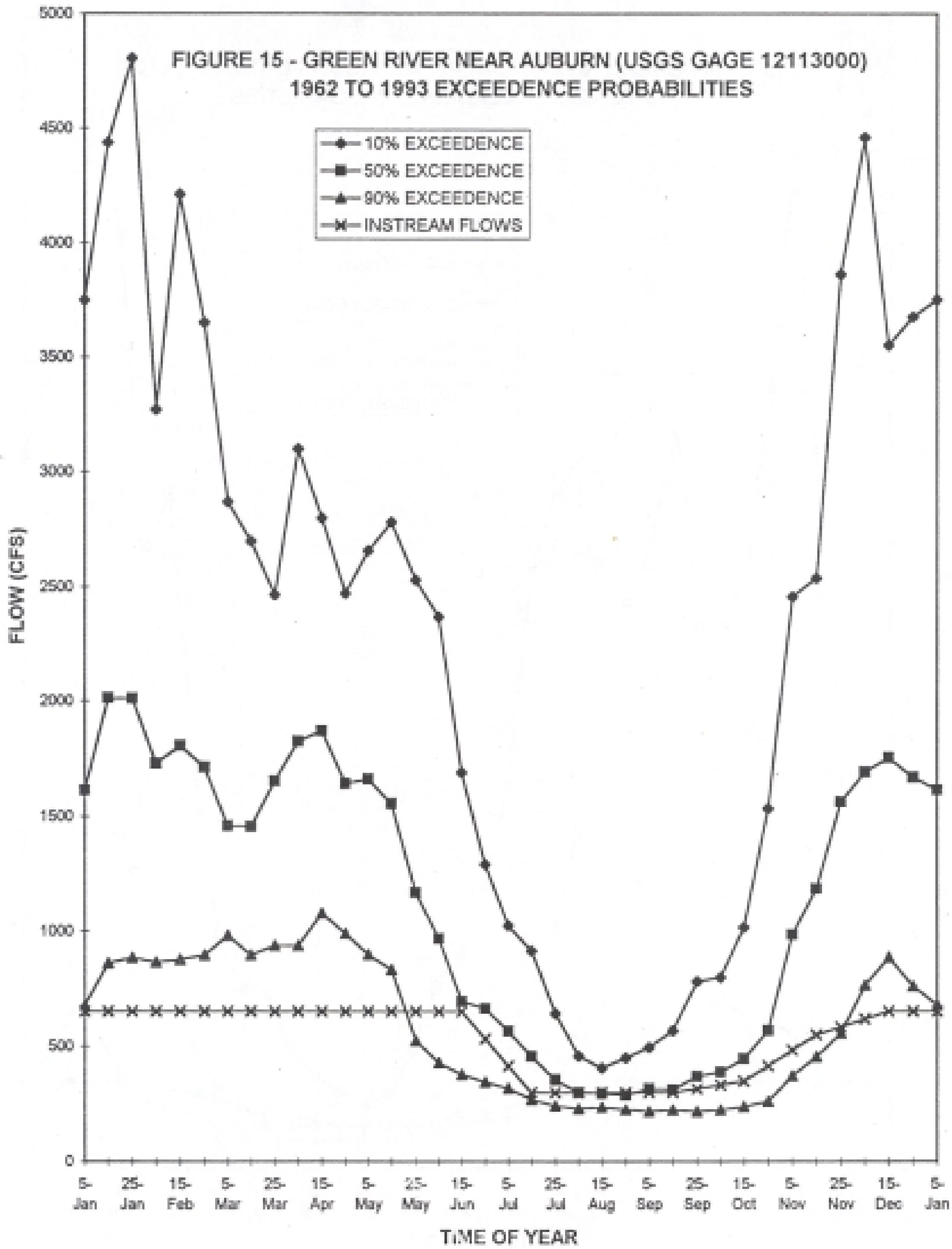


FIGURE 15 - GREEN RIVER NEAR AUBURN (USGS GAGE 12113000)
1962 TO 1993 EXCEEDENCE PROBABILITIES
10% EXCEEDENCE
50% EXCEEDENCE
90% EXCEEDENCE
INSTREAM FLOWS
FLOW (CFS)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5-Jan
25-Jan
15-Feb
5-Mar
25-Mar
15-Apr
5-May
25-May
15-Jun
5-Jul
25-Jul
15-Aug
5-Sep
25-Sep
15-Oct
5-Nov
25-Nov
15-Dec
5-Jan
TIME OF YEAR

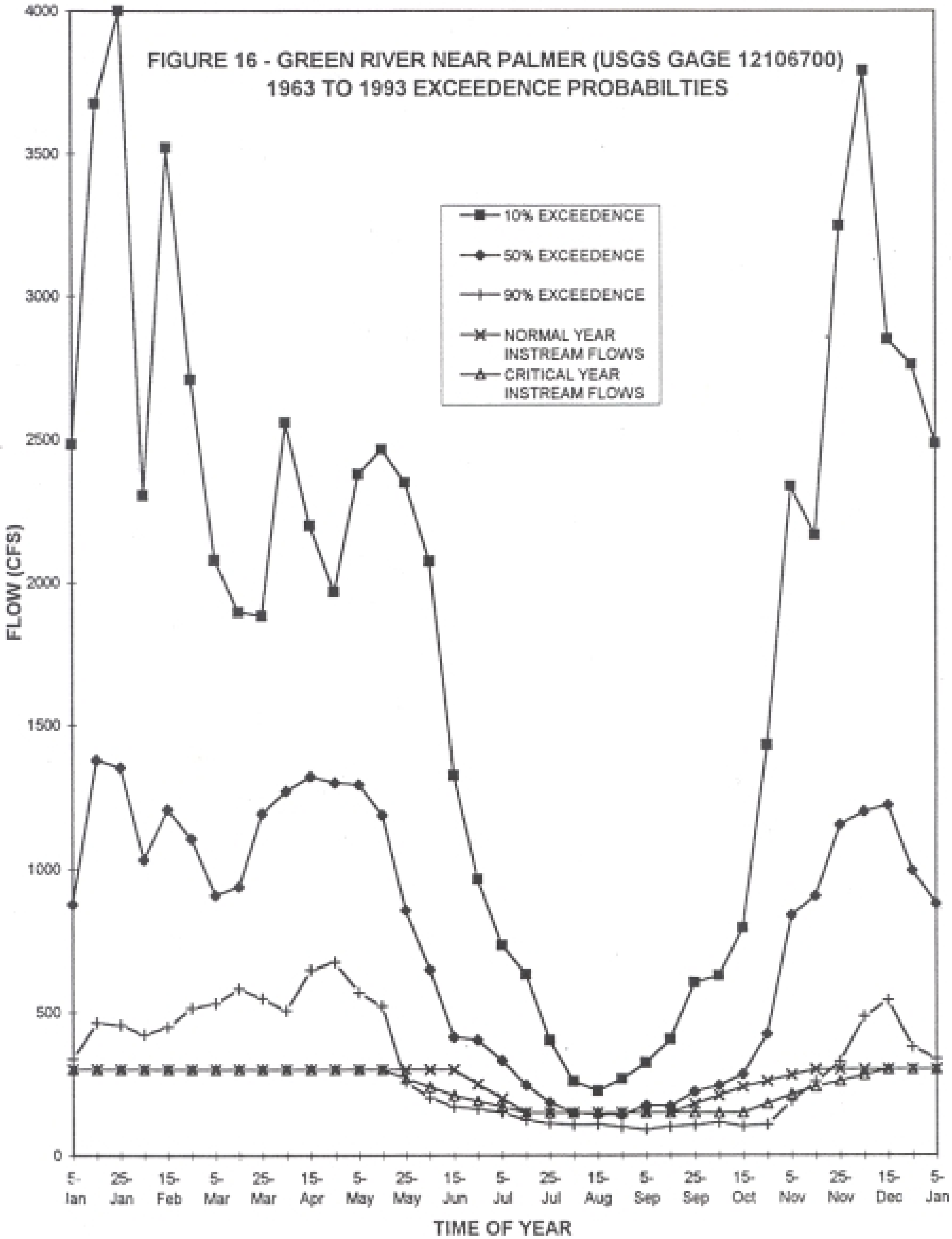


FIGURE 16 - GREEN RIVER NEAR PALMER (USGS GAGE 12106700)
1963 TO 1993 EXCEEDENCE PROBABILTIES
10% EXCEEDENCE
50% EXCEEDENCE
90% EXCEEDENCE
NORMAL YEAR INSTREAM FLOWS
CRITICAL YEAR INSTREAM FLOWS
FLOW (CFS)
TIME OF YEAR
0
500
1000
1500
2000
2500
3000
3500
4000
5-Jan
25-Jan
15-Feb
5-Mar
25-Mar
15-Apr
5-May
25-May
15-Jun
5-Jul
25-Jul
15-Aug
5-Sep
25-Sep
15-Oct
5-Nov
25-Nov
15-Dec
5-Jan

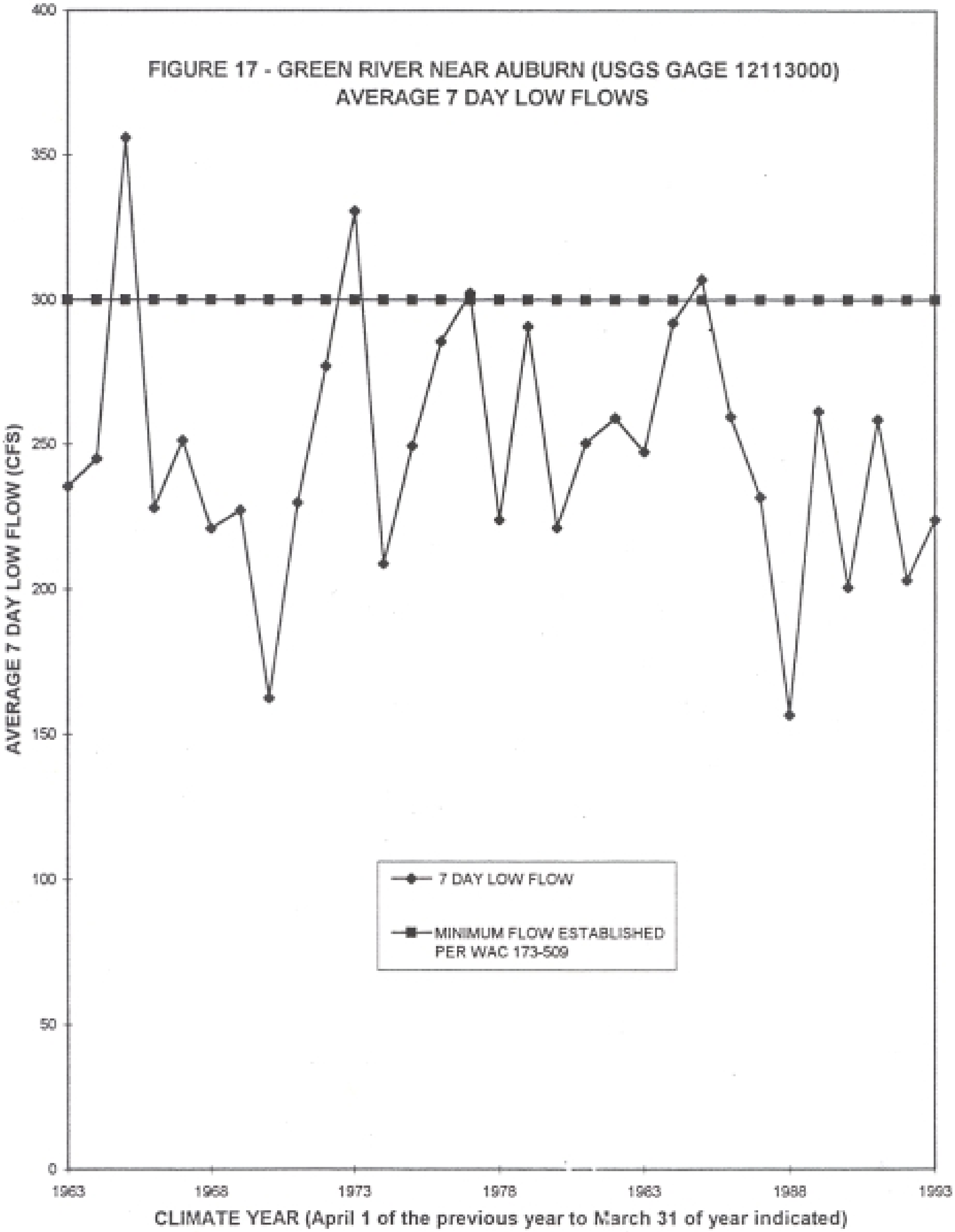


FIGURE 17 - GREEN RIVER NEAR AUBURN (USGS GAGE 12113000)
AVERAGE 7 DAY LOW FLOWS
AVERAGE 7 DAY LOW FLOW (CFS)
400
350
300
250
200
150
100
50
0
1963
1968
1973
1978
1983
1988
1993
CLIMATE YEAR (April 1 of the previous year to March 31 of year indicated)
7 DAY LOW FLOW
MINIMUM FLOW ESTABLISHED
PER WAC 173-509

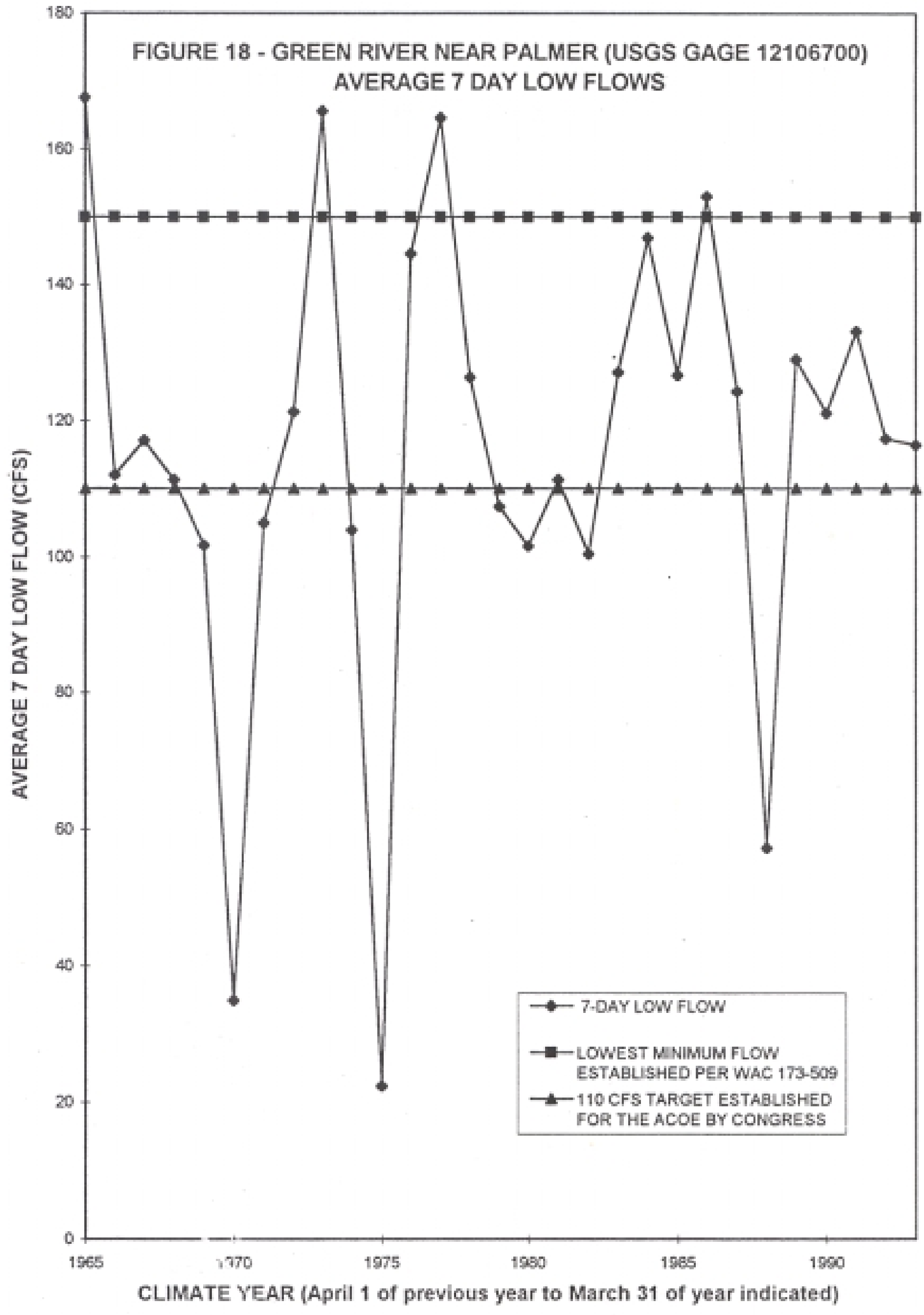


FIGURE 18 - GREEN RIVER NEAR PALMER (USGS GAGE 12106700)
AVERAGE 7 DAY LOW FLOWS
AVERAGE 7 DAY LOW FLOW (CFS)
180
160
140
120
100
80
60
40
20
0
1965
1970
1975
1980
1985
1990
CLIMATE YEAR (April 1 of previous year to March 31 of year indicated)
7-DAY LOW FLOW
LOWEST MINIMUM FLOW
ESTABLISHED PER WAC 173-509
110 CFS TARGET ESTABLISHED
FOR THE ACOE BY CONGRESS

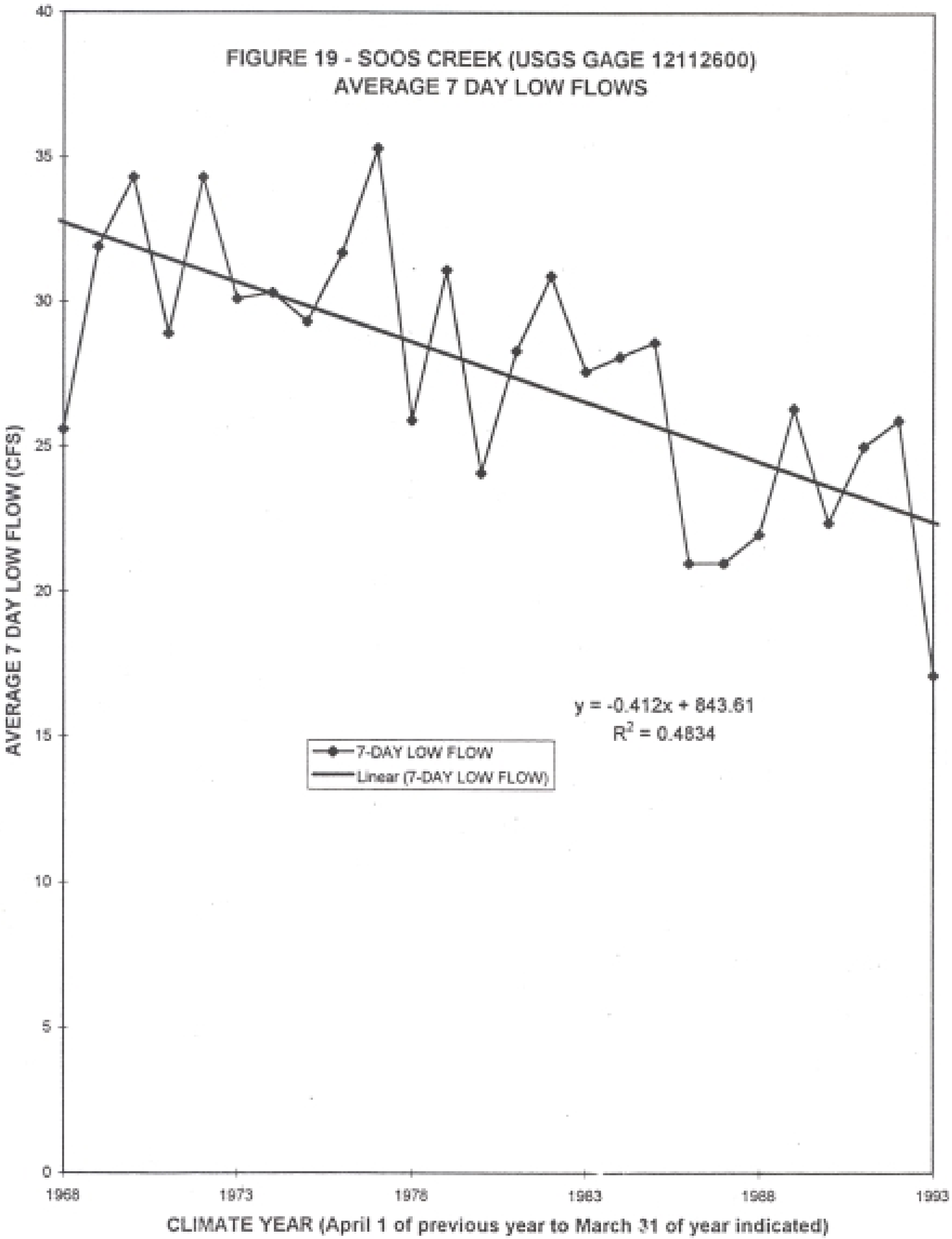


FIGURE 19 - SOOS CREEK (USGS GAGE 12112600)
AVERAGE 7 DAY LOW FLOWS
AVERAGE 7 DAY LOW FLOW (CFS)
y = -0.412x + 843.61
R^2 = 0.4834
7-DAY LOW FLOW
Linear (7-DAY LOW FLOW)
0
5
10
15
20
25
30
35
40
1968
1973
1978
1983
1988
1993
CLIMATE YEAR (April 1 of previous year to March 31 of year indicated)

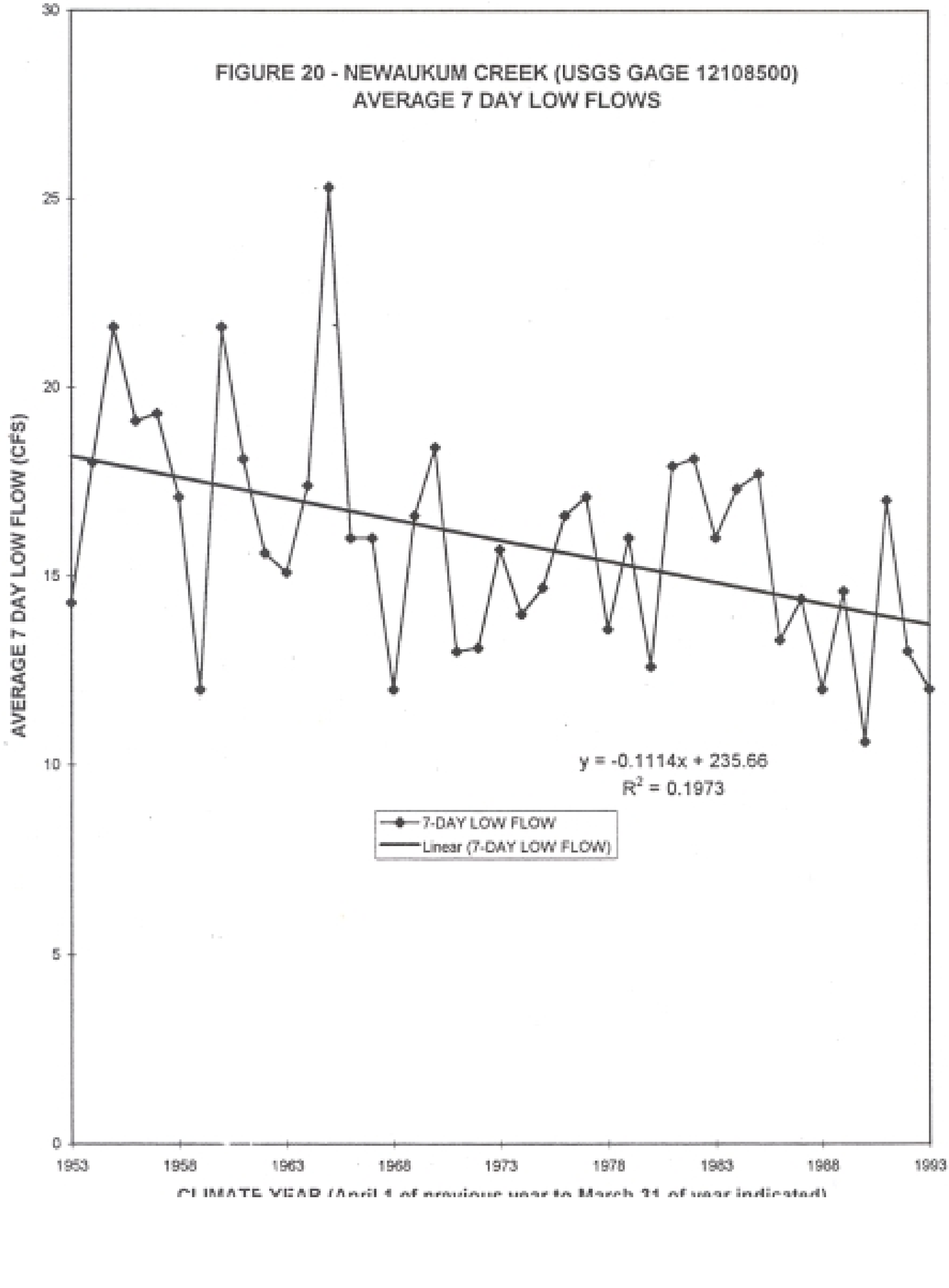


FIGURE 20 - NEWAUKUM CREEK (USGS GAGE 12108500)
AVERAGE 7 DAY LOW FLOWS
AVERAGE 7 DAY LOW FLOW (CFS)
y = -0.1114x + 235.66
R2 = 0.1973
7-DAY LOW FLOW
Linear (7-DAY LOW FLOW)
30
25
20
15
10
5
0
1953
1958
1963
1968
1973
1978
1983
1988
1993

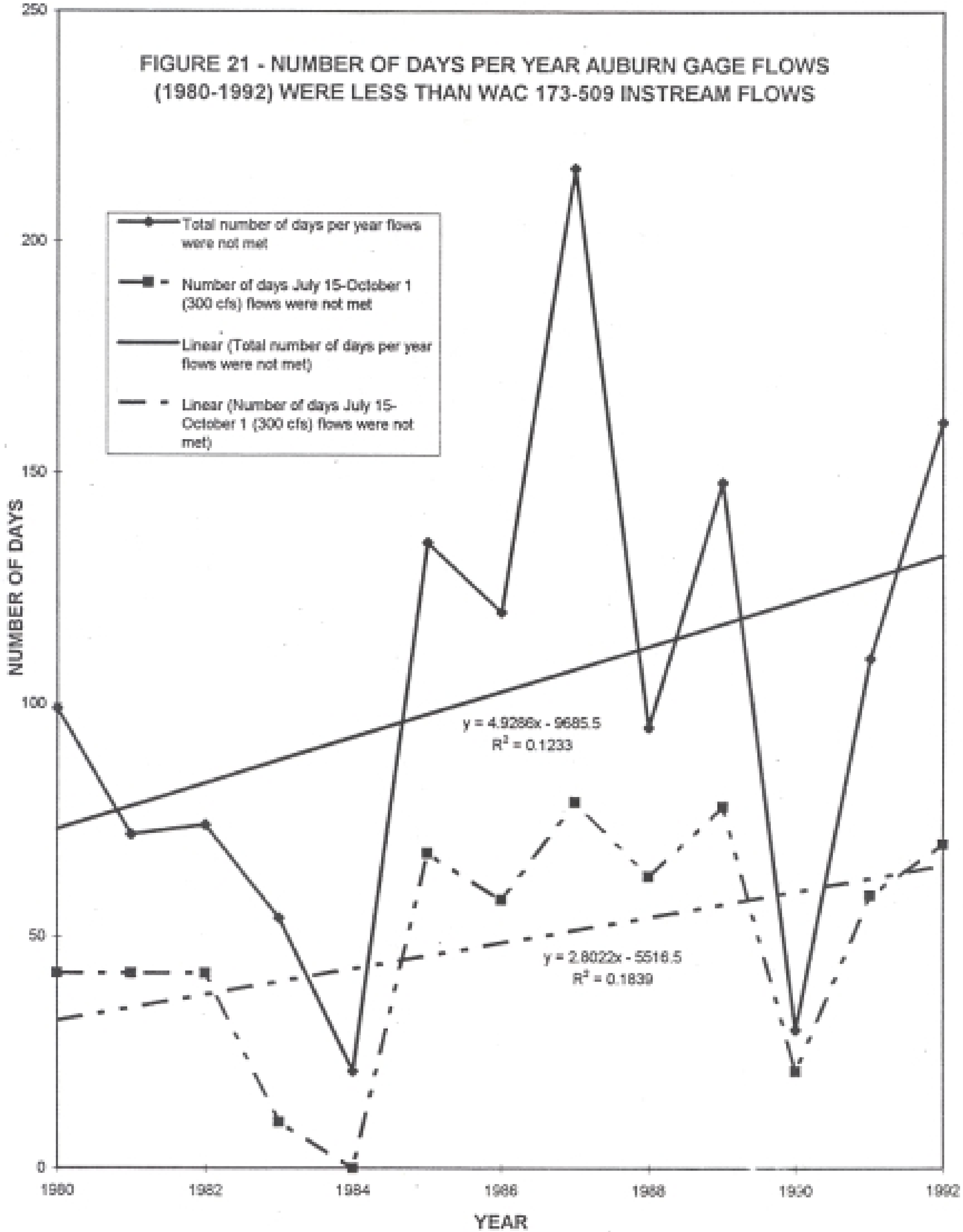


FIGURE 21 - NUMBER OF DAYS PER YEAR AUBURN GAGE FLOWS
(1980-1992) WERE LESS THAN WAC 173-509 INSTREAM FLOWS
Total number of days per year flows were not met
Number of days July 15-October 1 (300 cfs) flows were not met
Linear (Total number of days per year flows were not met)
Linear (Number of days July 15-October 1 (300 cfs) flows were not met)
y = 4.9286x - 9685.5
R² = 0.1233
y = 2.8022x - 5516.5
R² = 0.1839
NUMBER OF DAYS
YEAR
0
50
100
150
200
250
1980
1982
1984
1986
1988
1990
1992

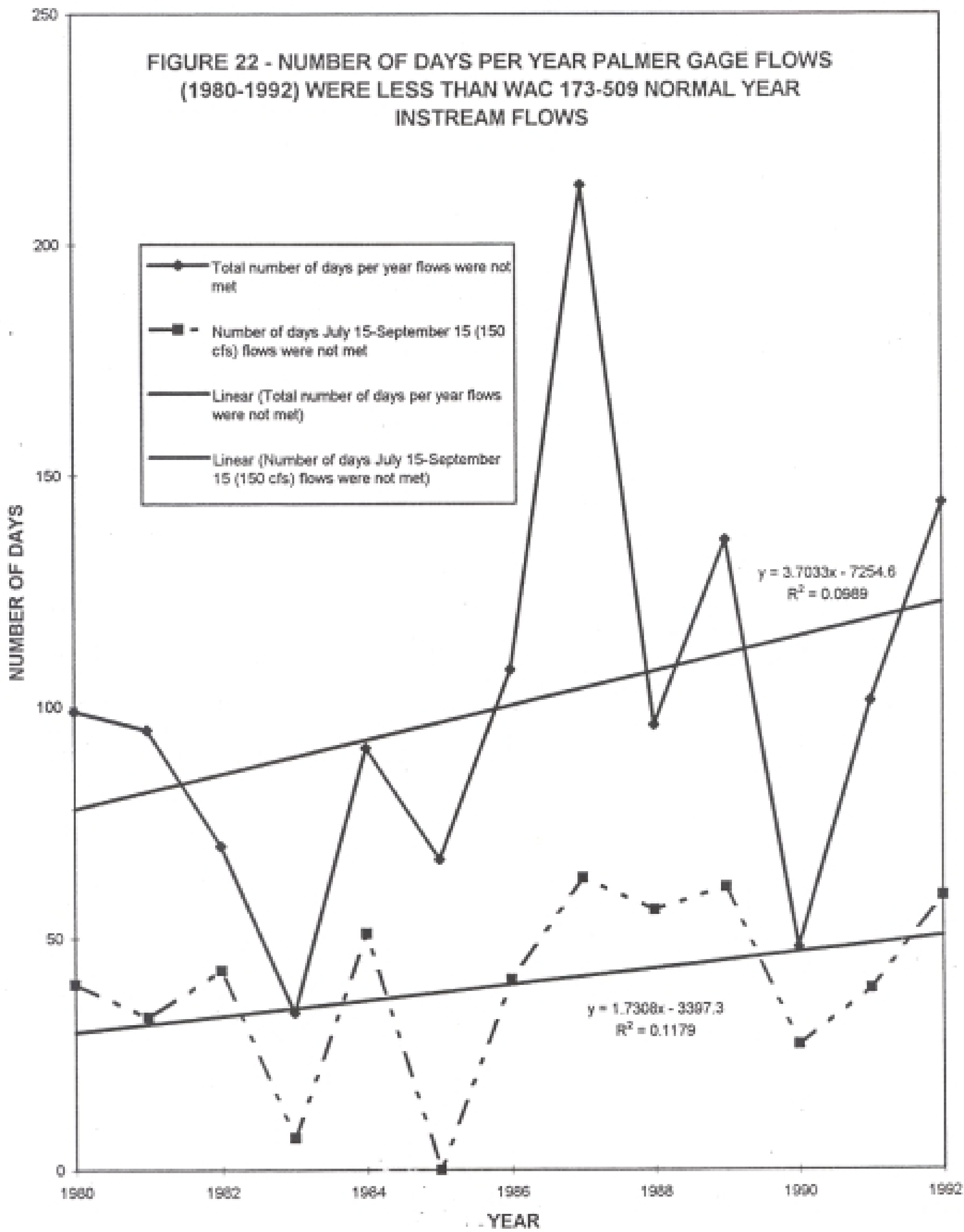


FIGURE 22 - NUMBER OF DAYS PER YEAR PALMER GAGE FLOWS (1980-1992) WERE LESS THAN WAC 173-509 NORMAL YEAR INSTREAM FLOWS
Total number of days per year flows were not met
Number of days July 15-September 15 (150 cfs) flows were not met
Linear (Total number of days per year flows were not met)
Linear (Number of days July 15-September 15 (150 cfs) flows were not met)
y = 3.7033x - 7254.6
R² = 0.0989
y = 1.7308x - 3397.3
R² = 0.1179
NUMBER OF DAYS
YEAR
0
50
100
150
200
250
1980
1982
1984
1986
1988
1990
1992

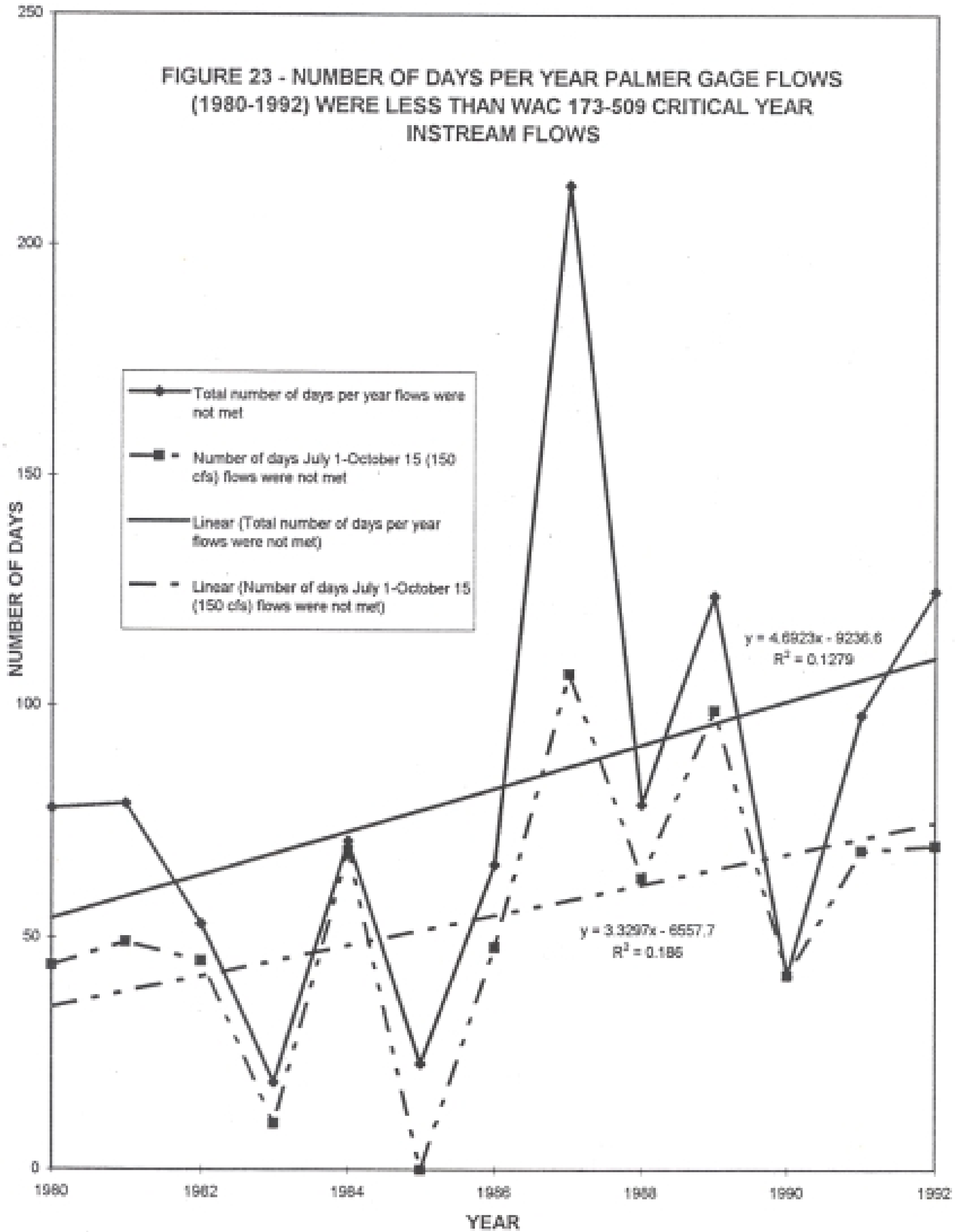


FIGURE 23 - NUMBER OF DAYS PER YEAR PALMER GAGE FLOWS
(1980-1992) WERE LESS THAN WAC 173-509 CRITICAL YEAR
INSTREAM FLOWS
Total number of days per year flows were not met
Number of days July 1-October 15 (150 cfs) flows were not met
Linear (Total number of days per year flows were not met)
Linear (Number of days July 1-October 15 (150 cfs) flows were not met)
y = 4.6923x - 9236.6
R^2 = 0.1279
y = 3.3297x - 6557.7
R^2 = 0.186
NUMBER OF DAYS
250
200
150
100
50
0
1980
1982
1984
1986
1988
1990
1992
YEAR

FIGURE 24 - COMPARISON OF DECLINING PRECIPITATION AT THE PALMER WEATHER STATION AND DECLINING FLOWS IN SOOS CREEK DURING 1967-1992

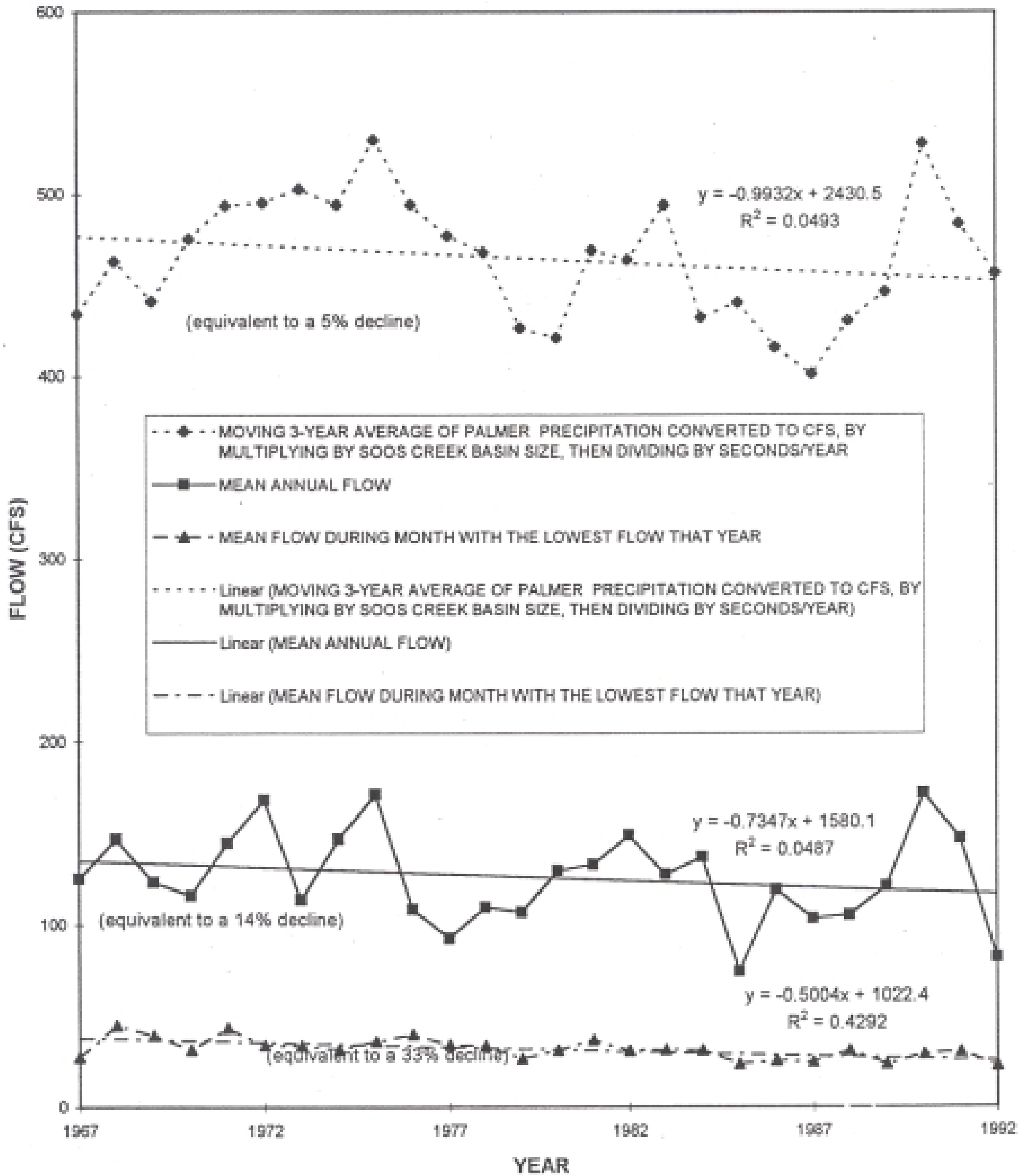


FIGURE 25 - COMPARISON OF DECLINING PRECIPITATION AT THE PALMER WEATHER STATION AND DECLINING FLOWS IN NEWAUKUM CREEK DURING 1953-1992

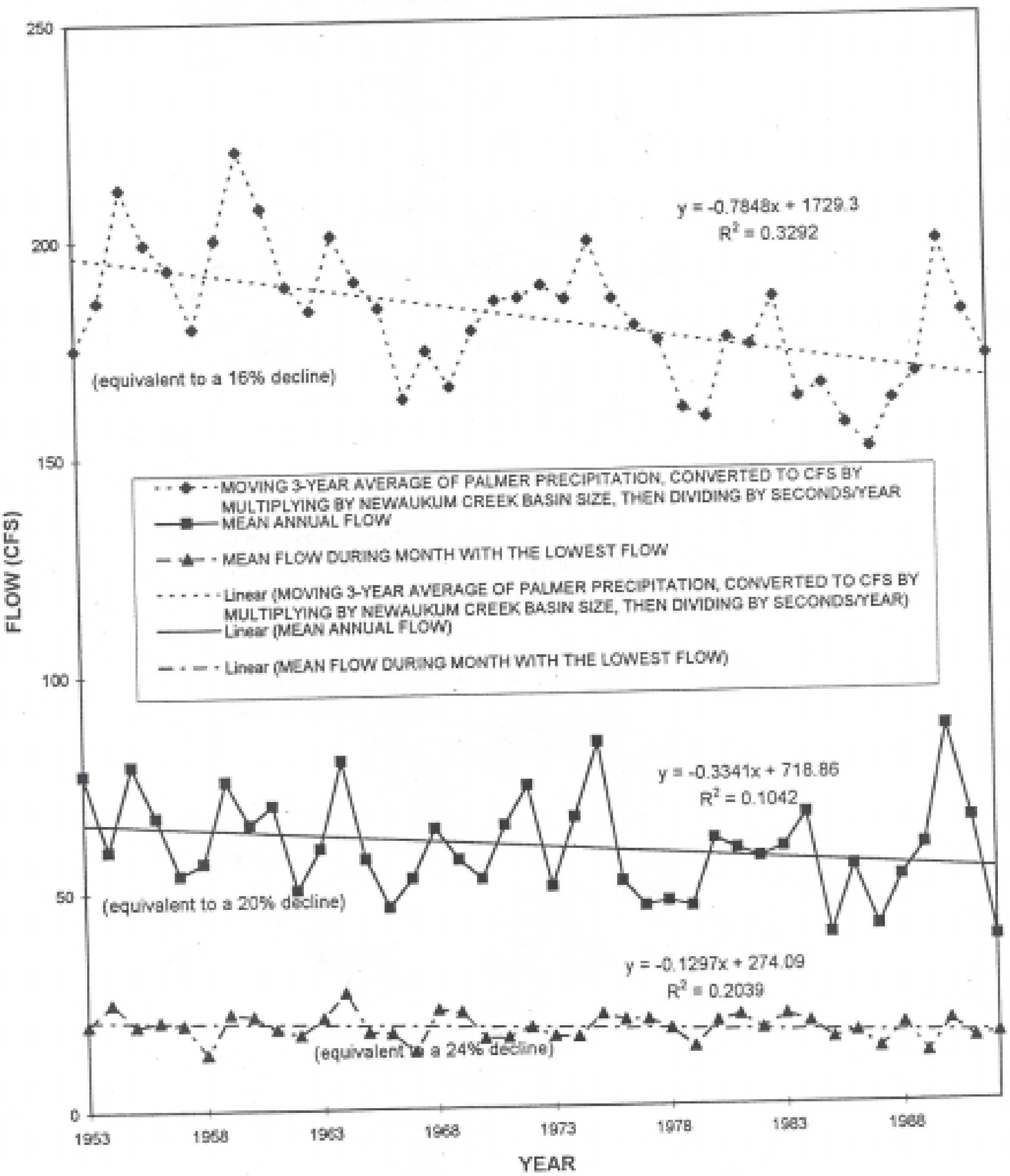
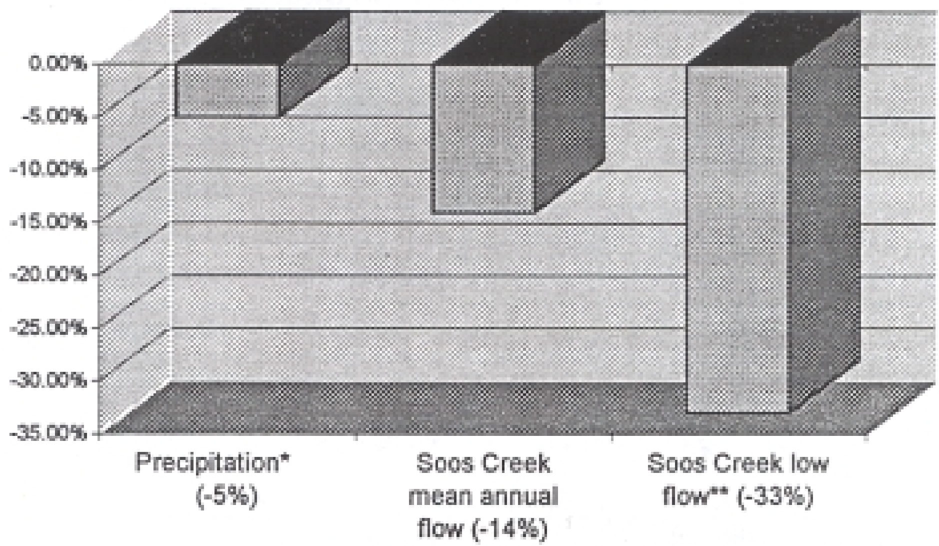


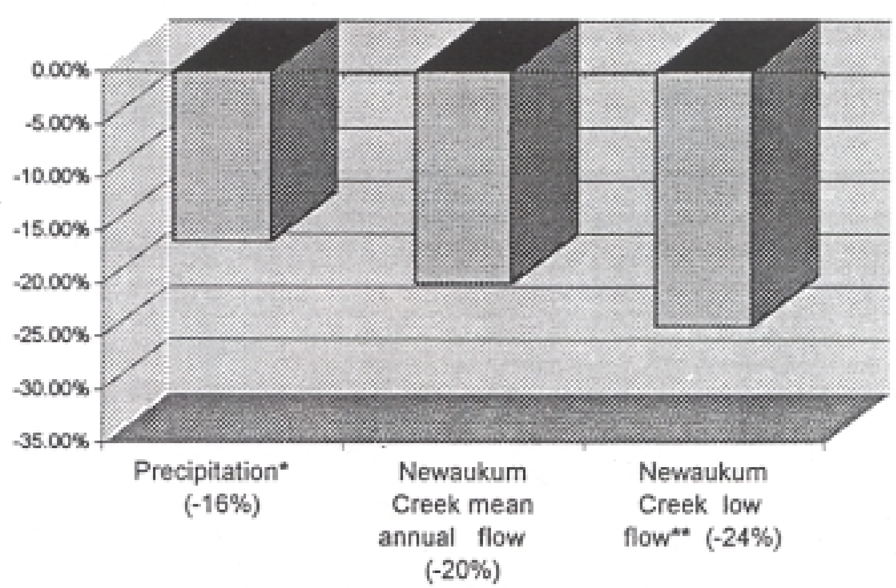
FIGURE 26 - COMPARISON OF DECLINING PRECIPITATION AT THE PALMER WEATHER STATION AND DECLINING FLOWS IN SOOS CREEK DURING 1967-1992



* Precipitaion at Palmer from 1967-1992

** Mean monthly flow during the month with the lowest flow

FIGURE 27 - COMPARISON OF DECLINING PRECIPITATION AT THE PALMER WEATHER STATION AND DECLINING FLOWS IN NEWAUKUM CREEK DURING 1953-1992



* Precipitation at Palmer from 1953-1992

** Mean monthly flow during the month with the lowest flow